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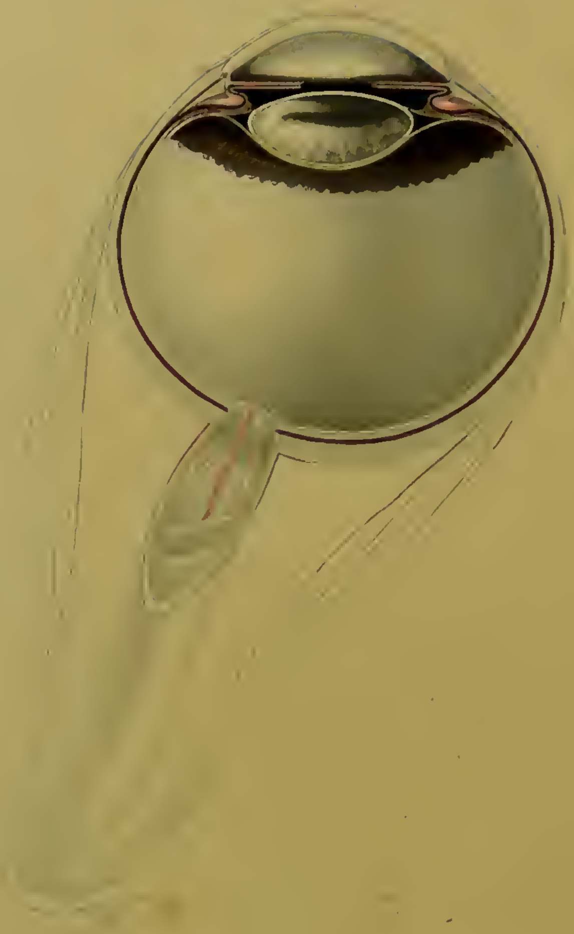

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THE

WISDOM AND BENEFICENCE
OF
THE ALMIGHTY
AS DISPLAYED IN
THE SENSE OF VISION.

(THE ACTONIAN PRIZE-TREATISE FOR 1851.)

BY T. WHARTON JONES, F.R.S.,
OPHTHALMIC SURGEON TO UNIVERSITY COLLEGE HOSPITAL.

> The hearing ear, and the seeing eye, the LORD hath made even both of them.—PROVERBS xx. 12.

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The Physiology of any one of the Senses (Touch, Taste, Smelling, Hearing, or Vision,) was the subject selected for the Essays, illustrative of the Wisdom and Beneficence of the Almighty, to be offered in competition for the Actonian Prize of One Hundred Guineas, in 1851, being the second septennial period.

The adjudication was made in my

favour by the Managers of the Royal Institution, for the Treatise which, by their liberal permission, I have now the honour to submit to the notice of the Public.

T. WHARTON JONES.

35, George Street, Hanover Square,
May, 1851.

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THE
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INTRODUCTION.

> O Lord, how manifold are thy works! in wisdom hast thou made them all: the earth is full of thy riches; *So is* this great and wide sea, wherein *are* things creeping innumerable, both small and great beasts.—Psalm civ. 24, 25.

The object of this Treatise is to show forth the wisdom and beneficence of the Almighty as displayed in those exquisite examples of his works, the Senses, and especially the Sense of Vision.

It is not sought to prove the existence of God; the declaration of Himself in His

Word is received as all-sufficient testimony on that point.

In thus resting our Faith on Revelation, we do not disregard the evidence of the being and attributes of God derived from Natural Theology. On the contrary, we believe that the existence of a Being, Infinite, Eternal, and Self-existent, All-wise, All-powerful, and Supremely Good, the First Cause and Original of all Things—the One God—can be abundantly proved by arguments both *à priori* and *à posteriori*. And, if any confirmation of the truths of Revelation be required, such arguments supply it. Still, it must be confessed that the God of Natural Theology is, at the most, a philosophical abstraction, "neglected," as observed by His Grace the present Archbishop of Canterbury, "by the philosopher himself, and unknown to the multitude; acknowledged in the closet and forgotten in the world."

With the surer and more intimate knowledge of God communicated in His Word, the intelligent mind contemplates His

Works, not so much as evidences of His existence as marks of His wisdom, power, and beneficence,—marks which it perceives in small things as well as in great. To the intelligent mind, indeed, the faintest star that twinkles in the firmament of heaven equally with the glorious luminary of our system,—the drop of rain equally with the mighty ocean,—the grain of sand on the sea-shore equally with the loftiest mountain,—the microscopical fungus equally with the gigantic Baobab,—the infusory animalcule equally with the largest whale, bear evidence to the wisdom and beneficence of their Almighty Creator.

But though in everything presented by the fair world around us,—from the smallest to the greatest,—marks of the wisdom and beneficence of God may be perceived, it is pleasing and instructive, in a high degree, to have our attention directed to instances in which, from the striking display of harmonious arrangement, wonderful contrivance, and adaptation of means to ends, wise forethought and beneficent design are more than usually conspicuous. Perhaps, the history of the Senses presents us with such instances of as interesting and instructive a character as are to be met with in the whole domain of Nature.

CHAPTER I.

OF THE SENSES IN THEIR RELATIONS TO THE OTHER FUNCTIONS OF THE ANIMAL BODY, AND OF THE RELATIONS OF THE WHOLE TO THE EXTERNAL WORLD.

He that planted the ear, shall he not hear? He that formed the eye, shall he not see? * * * He that teacheth man knowledge, *shall not he know?*—Psalm xciv. 9, 10.

Without entering into an examination of the more minute points of difference between plants and animals, it may be broadly stated that these two great divisions of organized and living beings are distinguished from each other especially in this: that animals, in addition to the functions which they possess in common with plants, are endowed with the faculties of sensation and voluntary motion,—faculties by means of which they are enabled to keep up an active relationship with the external world—to perceive the impressions made on them by surrounding bodies on the one hand, and, on the other, to execute definite movements for the purpose of withdrawing themselves from some, and putting themselves into closer connection with others.

That, in this collocation of the faculties of sensation and motion, there is wise and beneficent design will be at once acknowledged, if we reflect on what would have been the condition of an animal endowed with the faculty of sensation, without the power to move towards objects it perceived to be beneficial, or from such as appeared to be hurtful;—or of an animal possessed of the means by which to move, without the faculty of perceiving that towards or from which its well-being required it should move. In the one case, sensation would have been a source of distress to the animal, whilst, in the other, the power to move would have been useless.

Besides the mere collocation of sensation and motion in animals, we find, if we trace these faculties throughout the series, a correlation in their development,—we see that in respect to their degree of perfection, the faculties of sensation and motion have constantly a direct mutual relation. Thus the lowest animals have the faculty of sensation extremely limited,—in fact, they are endowed merely with tactile sensibility,—but as we ascend in the scale we find special senses of touch, taste, smelling, hearing, and vision, in greater or less number and perfection. In correspondence with this, we perceive that in the lowest animals the power to move is limited, but that it is enjoyed by the higher animals in a great degree.

We have thus, in the correlations of the faculties of sensation and motion, as regards development, the same wise and beneficent design carried out in detail, which strikes us in its general manifestation when we contemplate these faculties merely in their collocation. Mr. Locke traces the design manifested in the correlations, in respect to development, of the faculties of sensation and motion in a very lucid and interesting manner. "We may," he says, "from the make of an oyster or cockle, conclude, that it has not so many nor so quick senses as a man, or several other animals. Nor if it had, would it, in that state and incapacity of transferring itself from one place to another, be bettered by them. What good would sight or hearing do to a creature that cannot move itself to, or from the object, wherein at a distance it perceives good or evil? And would not quickness of sensation be an inconvenience to an animal that must be still where chance has once placed it, and there receive the afflux of colder or warmer, clean or foul water, as it happens to come to it?"

The faculties of sensation and motion, besides being in adaptation to each other, are so likewise to the external circumstances in which the animal is placed. Thus in animals even high in the scale, that live in places to which light does not penetrate, as the mole underground, the sense of vision not being required, is not developed—the eyes are merely rudimental. The other senses, however, the exercise of which is necessary, and not hindered by the circumstances wherein the animal is placed, are duly developed. In regard to the faculty of motion in the mole, it also is in adaptation to the underground habits of the animal; the limbs being formed like spades fitted for digging, whilst the shape of the body as a whole is that best adapted for progression through the passages excavated by the action of the extremities.

Whilst then it is evident that the Creator wisely left undeveloped the eyes of the mole, which he saw would not be necessary, (though the rudiment of the organ was preserved in subordination to the plan or type according to which the animals, of the division to which the mole belongs, are framed;) it is also evident, that he beneficently planned the motor apparatus to answer the purposes for which, by reason of the very habits which rendered the eyes unnecessary, they were required.

Again, in animals to which the sense of vision is equally necessary for their exigencies, but which live in different media, the structure of the optical part of the eye is modified in accordance with the difference in the manner in which the light, on entering that organ from a given medium, will be bent or refracted. A comparison of the eyes of a fish with those of land animals, especially birds, to be made below, will demonstrate this.

But it is not alone between the faculties of sensation and locomotion, that a wisely and beneficently designed correspondence is to be perceived. Such may be discovered also with respect to the other classes of functions. And herein we see how that everything in Nature is linked together in a chain—how that all things fit with each other,—showing at once the unity of design and of the designer. Whilst the degree of sensibility an animal is endowed with, and the activity of its locomotion are in intimate mutual relation, they, in their turn, influence the means by which the nutrition of the individual animal and the reproduction of the race are accomplished. The higher animals, for example, endowed with sensibility in an exquisite degree, and along with this, possessing the power to move freely from one place to another, in order to react on the surrounding objects, have their nutritive and reproductive functions very complicated; but in the lowest animals, the polyp, for instance, the extent of whose sensibility is extremely limited—confined to the tactile sensibility of its tentacula,—and which is fixed to one spot,—incapable of any other movement than that of its tentacula in the prehension of food—nutrition and reproduction are comparatively very simple acts.

CHAPTER II.

OF THE NATURE OF THE SENSES GENERALLY.

Whence is it that Nature doeth nothing in vain, and whence arises all that Order and Beauty we see in the World? How came the Bodies of Animals to be contrived with so much Art, and for what Ends were their several Parts? Was the Eye contrived without Skill in Optics, and the Ear without Knowledge of Sounds?—NEWTON'S OPTICS, Query 28.

THE Senses are five in number, viz. Touch, Taste, Smelling, Hearing, and Vision; and their organs are respectively, the Hand, the Tongue, the Nose, the Ear, and the Eye.

An organ of sense is composed essentially of a proper nerve, one extremity of which is connected with the brain, the other, with an apparatus placed at the surface of the body fitted to transmit to the nerve the external agent which is to make the impression on it. For this purpose, the apparatus of each organ of sense is constructed in special adaptation to the physical nature of the external agent which it has to transmit to the nerve.

To exemplify this, we may take the organs of vision and hearing.

The nerves of vision are the optic nerves. Each optic nerve is, at one extremity, connected with a very central part of the brain, and, at the other, expanded into a cup-shaped nervous membrane called the *Retina*, which lines the interior of the back part of the eyeball. The part of the eyeball in front of the retina is an apparatus constructed in special adaptation to the physical nature of the agent LIGHT, which it has to transmit to the retina, and through the medium of which it is, the eye takes cognizance of other external objects. The apparatus, in short, in front of the retina is a *dioptric* one.

The nerves of hearing are the auditory nerves; each of which is, by one extremity, connected with the brain and by the other extremity, which is peculiarly expanded in the innermost cavities of the ear, with an apparatus constructed specially for the transmission of SOUND,—with an *acoustic* apparatus, in short.

From this brief account of the organs of vision and hearing, we may already venture to declare, in answer to Newton's query, that the eye was certainly not constructed without skill in optics, nor the ear without knowledge of sounds.

The general mechanism by which the impression made by external objects on an organ of sense is communicated through the nerve to the brain, may perhaps be illustrated by a reference to the plan of the electric telegraph.

Suppose a message by the electric telegraph from Portsmouth to the Admiralty in Whitehall be taken for an example, on the one hand, and the transmission of a visual impression to the brain for an example on the other :—

The wire extending from Portsmouth to the Admiralty may be compared to the optic nerve. At the Portsmouth end of the wire, there is an apparatus which may be compared to the eyeball; whilst at the Admiralty end, there is a different kind of apparatus with an indicator-needle, which may be compared to that part of the brain with which the central extremity of the optic nerve is connected.

When the apparatus at the Portsmouth terminus is acted on, electricity is transmitted from it along the wire, and deflections of the indicator-needle of the apparatus at the Admiralty are thereby determined. According to the manner in which the apparatus at Portsmouth is acted on, the electricity transmitted is positive or negative, and according to this, the indicator-needle at the Admiralty is deflected to the right or left.

From the deflections of the indicator-needle, a person at the Admiralty can interpret the information which the person at the Portsmouth terminus intends to communicate by the particular manner in which he acts on the apparatus under his direction.

When the eye is impressed by light, a change in the state of the retina is induced, which determines the transmission of a certain influence along the optic nerve to the brain in a manner, let it be assumed, in some degree analogous to that in which, when the apparatus at Portsmouth is acted on, the electrical influence is transmitted along the wire to the Admiralty.

As changes in the direction of the indicator-needle of the apparatus at the Admiralty are induced by the electrical influence thus transmitted, so a change of state is induced in the brain by the transmission of the influence from the retina to it along the optic nerve.

Of the change of state of the brain, the mind is rendered conscious by the sensation of light and colour, and according to the modifications of the sensation, it infers the nature of the impression made on the eye in some such manner, let it be assumed, as the person at the Admiralty interprets, from the pointing of the indicator-needle, the meaning of the communication from Portsmouth made by acting on the apparatus at the latter place.

By the above comparison with the electric telegraph, the reader will perhaps be assisted in forming some conception of the admirable nature of the general mechanism of the senses. We all readily understand the ingenuity which designed the electric telegraph, and are delighted with the wonderful results of its operation—the almost instantaneous communication of intelligence from one place to another hundreds of miles apart. But although we are familiar with the still more admirable results of the operation of the senses, few persons make them the subject of abstract contemplation, and thus perceive fully the wisdom and beneficence of design manifest in their general plan. More perfect than the electric telegraph, they are self-acting. No intermediate agent is required at the outport or organ of the sense to make an impression on it—the impressions are directly made, and the phenomena thus telegraphed to the mind as they occur.

Having considered the admirable character of the general mechanism of the senses —how we take cognizance of external objects by them,—we have now to turn our attention to the nature of the knowledge of external objects which we gain through the senses.

By the impression of an external object on a sense, we have seen that a certain change in the state of its nerve is induced; and that, by the communication of this change of state from the nerve to the brain, the mind is rendered conscious of a sensation. A sensation, then, is all that we can perceive as a result of the impression of an external object on a sense. Of the external object we can take no direct cognizance, but we indirectly judge of its qualities by the characters of the sensation excited in us by its impression on the senses.

The sensation of which we are conscious

as a result of an impression on a nerve of sense, it is to be particularly remarked, is thus not any quality of the external object which makes the impression, though in common language we speak as if it were. The sensation, for example, which we experience in consequence of an impression on the eye, we denominate *light*, and the external agent which commonly causes the impression, we also call *light*. But the sensation and the external agent, which, by its impression on our optic nerve, excites in us the sensation, are totally different things.

In illustration of this, it is to be stated, that the sensation of light can be called forth by the impression on our eyes of other external agents besides that which is specially called *light*. Thus, let the eyes be impressed mechanically, by electricity or otherwise, no other sensation will result but that of *light*. In short, it is on the nature of our optic nerves, and not on the nature of the agent which impresses them, that the *sensation of light* depends.

If it were possible for the surface of the retina to be directly pressed on by types,—types turned upside down,—we should, though in the dark, see before our eyes *light letters* projected on a black ground. Such pressure on the retina by types is of course not possible, but well-defined pressure on the retina by its own blood-vessels when over-distended with blood is possible; and as a result of the pressure we may sometimes see before our eyes, though in the dark, a light image of the branchings of the retinal blood-vessels.

What has now been said of the optic nerves and their sensations is equally applicable to the other nerves of sense and their sensations. To take, for example, the auditory nerves:—The sensation excited in us by an impression on the ear we call *sound*, and the external agency, which commonly causes the impression, we also call *sound*. But the sensation of sound and the external agency which, by its impression on our auditory nerves, excites in us the sensation, are, as in the case of the sensation of light and agent light, totally different things.

As pressure on the retina of the eye, by its own blood-vessels, when over-distended with blood, will excite a visual appearance, so pressure on the expansion of the auditory nerve within the ear, by its own blood-vessels, in a similar state of over-distension, will produce sonorous sensations. As a blow on the eye will give rise to the *sensation of light*, so, as every one knows, a box on the ear will occasion the *sensation of sound.*

Each nerve of sense is thus capable of communicating to the mind one particular kind of sensation only, whatever be the nature of the agent which impresses it, though that sensation may be variously modified. One nerve of sense thus cannot really communicate the sensation of another. In short, we cannot hear with the eye, nor see with the ear. Notwithstanding this, the mind has been so beneficently endowed that it can, in some measure, make up for the loss of one sense by inferences from the information it receives through the other senses, to which it at the same time directs increased attention. Thus persons deprived of hearing may learn to comprehend what is said by watching with the eye the movements of the lips, &c., of the speaker, which movements they interpret as signals from a distance are interpreted. Blind persons also have learned to determine in an analogous indirect manner by means of the hearing what can only be directly observed by vision or touch.

Though the sensation peculiar to a nerve of sense may thus be excited by the impression on the latter of various external agencies, it is most important to observe that certain external agents do stand in a specific relation, as regards action, to certain nerves of sense, call forth, by their impression, the sensation peculiar to them in the most intense manner, and are their ordinary stimuli. Thus, the external agent named *light* calls forth, in the most intense degree, the specific sensation of the optic nerves by its impression on them; whereas, mechanical or electrical irritation does so in comparatively an imperfect manner.

In correspondence with this specific relationship of certain external agencies to certain nerves of sense, the structure of the organs of sense, we have seen, has been designed. Thus the structure of the eyeball is in special adaptation to the physical nature of the external agent *light*, which stands, in the specific relationship just mentioned, to the optic nerve, and is its ordinary stimulus. And so of the other organs of sense; the structure of each being in strict adaptation to the physical nature of the ordinary stimulus of its nerve,—an adaptation manifesting beneficent design guided by the most comprehensive wisdom, and unerringly carried into effect by power the most absolute.

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CHAPTER III.

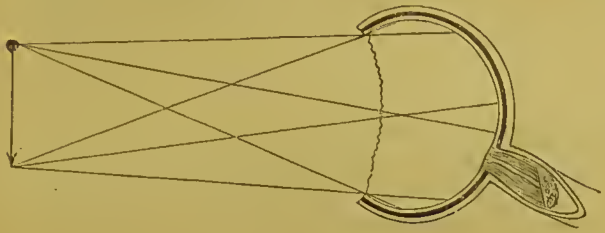
OF THE SENSE OF VISION IN PARTICULAR.

> Nihil est, in quo manifestius Geometriæ artem Deus exercuerit.
>
> There is nothing in which God has more manifestly exercised the art of Geometry than in the eye.
>
> HUYGENS' COSMOTHEOROS.

EXTERNAL objects are visible only inasmuch as they give out light from themselves, or, receiving it from other bodies, reflect it; for the light thus given out or reflected is the medium through which external objects impress the eye, and excite a visual sensation.

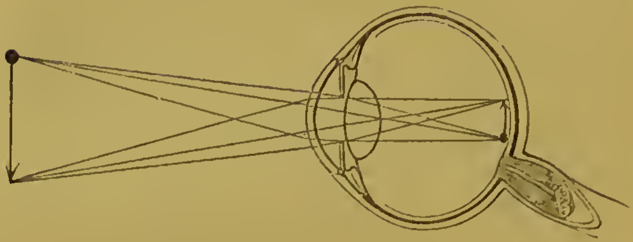
The rays of light diverge in straight

lines from the several points of an object. Now, if the retina or expansion of the optic nerve, which receives the impression, had been equally exposed all over its surface to the rays of light thus diverging, we should



have been sensible merely of a uniformly luminous field before the eyes, but could have perceived no form—no object.

By means of a dioptric apparatus in front of the retina, however, the rays of light diverging from the several points of an object are made to converge, and at length to impinge in so many distinct points or foci on that nervous membrane. The result is, that there is projected on it an image of the external object, whence the rays of light, entering the eye, emanate or are reflected, thus:—



The consequence of the impression so made on the retina is, that we have a sensation of light in various degrees of intensity and colour, depending on the quantity and quality of the rays of light making the impression, and of a form and extent, depending on the form and extent of the part of the retina impressed,—in short, we have a visual sensation by which the mind perceives the object, or, in common language, *we see* it.

From the preceding diagram it will be observed that the eyeball is, optically speaking, a true camera obscura—a camera obscura perfected by dioptrical contrivances—the retina being the table on which the images are projected,—the iris, the shutter,—the pupil, the hole in the shutter,—and the lenticular humours, together with the watch-glass shaped cornea, the dioptric parts.

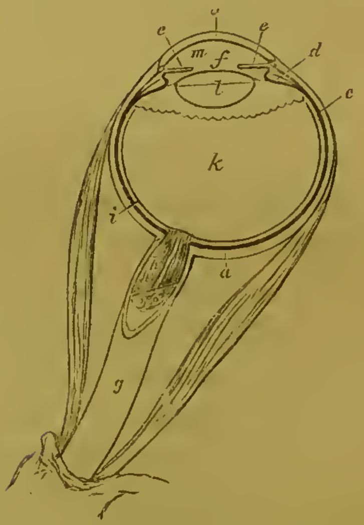
SECTION I.

Of the human eye considered as a camera obscura.

The admirable discovery of the art of fixing and rendering permanent the fleeting pictures of the camera obscura, has thrown additional interest around that most exquisite instrument; and the ingenuity and skill of the optician have been so successfully exerted in its improvement, that our admiration is now divided between the excellence of the instrument itself and the beauty of the art founded on its application.

If there is so much to admire and delight in the mechanism of the camera obscura and in the daguerreotype or kalotype process—so much of wisdom and skill—such adaptation of means to ends—what shall we say of the natural camera obscura, the eye,—of its application to project images of external objects on the retina, and of the wonderful result founded on that application, viz. the perception by the mind of the external object? For the present we shall speak only of the eye considered as a camera obscura.

§ *Of the structure of the eyeball.*



Horizontal section of the right human eyeball, natural size.*

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* The frontispiece represents the same double the natural size.

The wall of the ocular chamber is composed externally of the strong fibrous *sclerotic coat* (*a*), except in front, where it is formed by the transparent *cornea* (*b*), which, like a window, closes in the front of the eyeball. The sclerotic coat is lined inside by one more delicate, called the *choroid coat* (*c*), which contains much dark pigment dispersed throughout its substance. Towards the place where the sclerotic joins the cornea, the choroid coat presents a peculiar plicated structure called *ciliary body* (*d*). On the inner surface of the choroid coat, again, there is a tessellated pavement-like work of flat hexagonal-shaped cells, of microscopical minuteness, filled with dark brown particles, forming the proper *pigment-membrane.*

As the optician obscures the interior of his camera by painting it black, in order that any extraneous rays of light may be absorbed, and thus prevented from being thrown by reflection on the table of the instrument and interfering with the distinctness of the image there formed,—so the

Almighty Maker of the eye has ordered that it should be obscured in the interior by the pigment-membrane. And here we have an illustration not less of beneficence than of wisdom, for had the interior of our eyes not been obscured, not only would our vision have been indistinct, but we should have suffered from a painful dazzling in the exercise of vision by daylight, as is the case with albinoes, in whom the pigment of the eye, as well as that of the skin, is deficient.

Situated behind the transparent cornea, and supported on both surfaces by the aqueous humour, is seen the *iris* (*ee*), a flat circular membrane, perforated by a round aperture called the *pupil* (*f*). The anterior surface of the iris, as seen through the transparent cornea in the living eye, is differently coloured in different individuals: indeed, it is the colour of the anterior surface of the iris, which, in common language, is spoken of as the colour of the eye generally; thus a blue eye or hazel eye means merely an eye with a blue iris or one with a hazel-coloured iris. The posterior surface of the iris is invested with a dark pigment-membrane, which is a modified continuation of that lining the inner surface of the choroid coat.

The iris perforated by the pupil, thus situated behind the transparent cornea, is, in the camera of the eye, what the shutter with the hole in it is in the primitive form of the camera obscura, or what a stop or diaphragm is in more perfect instruments. But, as we shall see, the iris with its pupil is a stop or diaphragm of infinitely higher workmanship than any that the skill of the optician can fashion. By means of the contractile power with which the iris is endowed, the pupil admits of being varied in size; but not alone this,—there is a provision by which the contractile power of the iris is called into operation under the very circumstances which require the variation in the size of the pupil, and that altogether independently of any effort on our part. Furthermore, the suspension of the iris in the aqueous humour allows of the motions of the pupil to take place much more readily than would have been the case had the iris been suspended in air. The iris with its pupil is, in short, not simply an adjusting stop or diaphragm in respect to aperture, but one which is variable and self-adjusting.

The wisdom and beneficence which planned the iris are well illustrated, in a negative way, by cases of malformation occasionally met with, in which it is congenitally absent. The unfortunate subjects of this defect are painfully impressed by the too great influx of light into the eye, so that, for relief, they seek the dark, and keep their eyebrows depressed and their eyelids half closed. Their vision is also imperfect; partly, from the dazzling which arises from the impression of too much light on the retina, and partly, in consequence of such optical aberrations as it is the function of the iris with its pupil to correct. Comparatively small amelioration of the latter defect is derived from the use of an artificial iris, or a dark plate with a small aperture in it, placed before the eye—a circumstance which is an illustration of the optical skill which gave the iris its particular position in the eye, for, as we shall see more fully below, the iris, with its pupil, is situated in the very part of the organ where it can act most advantageously as a stop or diaphragm, without unnecessarily intercepting too much light.

The *retina* (*i*) or expansion of the optic nerve, it has been above mentioned, lines the interior of the back part of the eyeball, being situated within the pigment membrane. It has the dioptric apparatus immediately in front, and is the table on which, in our ocular camera obscura, the image of external objects is projected.

The dioptric apparatus of the eye consists of the *vitreous humour*, the *crystalline lens*, the *aqueous humour*, and the *cornea.*

The *vitreous humour* (*k*) is a transparent jelly-like mass, which fills up the posterior and middle part of the interior of the eyeball. It is concavo-convex in shape. Its convexity, which is behind, affords the retina a surface, to spread itself uniformly upon. In its concavity, which is directed forwards, the crystalline lens lies imbedded.

The *crystalline lens* (*l*) is double convex, but unequally so. The more convex surface is the posterior, and is sunk in the concavity which the vitreous humour presents anteriorly.

In front of the crystalline lens is the *aqueous humour* (*m*), which owes its shape to that of the space wherein it is contained. The space in question, called the *aqueous cavity*, is convex anteriorly and concave posteriorly: being bounded in the former direction by the posterior and concave surface of the cornea, and in the latter direction by the anterior convex surface of the crystalline lens. Furthermore, the aqueous cavity is divided by the iris into two compartments—communicating through the pupil,—called the *anterior and posterior chambers of the aqueous humour.*

Lastly, the transparent watch-glass shaped *cornea*, at the same time that it closes in the front of the eyeball, forms an important part of the dioptric apparatus.

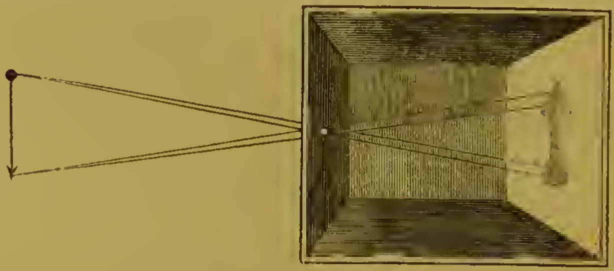
§ *Of the projection of images on the retina.*

The preceding brief description of the structure of the human eyeball will have given some idea of this camera obscura of divine workmanship. In the performance of the instrument, which we now proceed to consider, we shall find equally as in its workmanship, manifestations of wisdom and beneficence.

We premise an explanation of the projection of images on the table of the camera obscura, in order that the excellence of the mechanism by which images are projected on the retina, may be more readily understood and appreciated.

It is a law of light, that its rays, as long as they continue in the same medium, proceed in straight lines. Of the rays of light which diverge in straight lines in all directions from the different points of any external object, some will enter a hole in the shutter of a window looking towards the object, while others will be stopped by the shutter. The rays which enter the hole continue their straight course within the chamber, the window of which is closed by the shutter, until they are stopped by the opposite wall, or by a sheet of white paper held up behind the hole in the shutter. On the wall, or on the sheet of paper, on which the rays of light are received, there is seen a picture of the external object whence the rays of light which entered the hole of the shutter came.

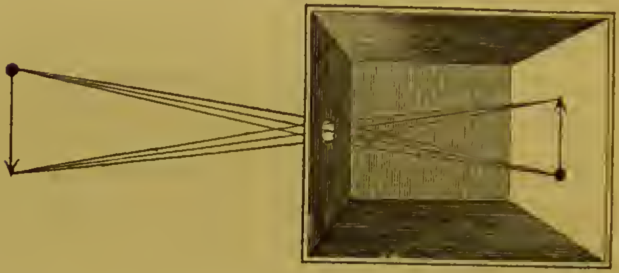
In regard to this picture, it is to be observed that it is inverted and ill-defined, thus:—



The cause of the inversion of the picture, it will be seen from the diagram, is that the rays of light from the upper part of the object which enter the hole, continuing their rectilineal progression within the chamber, necessarily impinge on the lower part of the wall or paper, while the rays from the lower part of the object as necessarily impinge on the upper part of the wall or paper; and so on with the rays from the sides and intermediate points of the object.

The cause of the imperfect definition of the picture again is, that the rays of light, which form it, do not impinge on the wall or paper in points or foci corresponding to those of the object whence they issued, but in a state of divergence, as may be seen in the diagram.

If a convex lens be inserted in the hole of the shutter, the image is no longer indistinct, but well defined when the sheet of paper on which it is projected is held at a certain distance behind the hole. The explanation of this is, that the rays of light diverging from all the different points of the object, are so bent or refracted from their original direction in passing through the convex lens, that they are rendered convergent, and so meet again in points or foci, as they fall on the sheet of paper, corresponding to those points of the external object whence they originally diverged, thus :—



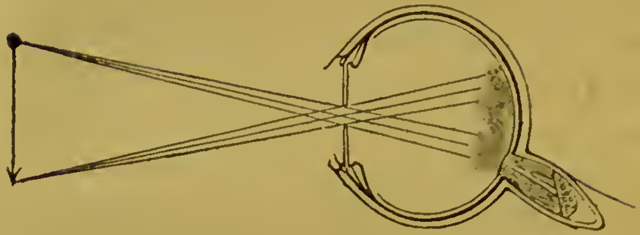
When there is no lens, the hole of the shutter requires to be small, in order that the picture projected on the sheet of paper may be as little diffused and indistinct as possible. Smallness of the hole produces this effect by giving passage only to the least divergent rays. But while the picture thus gains from improved definition, it loses from defective illumination, as but few rays make their way through the small hole.

When there is a lens, the hole of the shutter may be enlarged without diminishing the definition of the picture, because the lens is capable of bringing even the more divergent rays to a focus. Whilst, in consequence of the action of the lens, the picture does not lose in definition by enlarging the hole in the shutter, it gains in distinctness from increased illumination in consequence of a greater quantity of rays of light being concentrated in its formation.

It will be seen from the diagram, that though distinct both from accurate definition and good illumination, the picture is still inverted, for the same reason that the picture formed without a lens in the hole of the shutter is inverted.

To come to the projection of images on the retina:

Had the eyeball been destitute of dioptric parts, but provided with a small pupil, though pictures of objects might still have been projected on the retina, they would have been ill-defined, like the picture in a simple camera obscura without a lens, thus:—



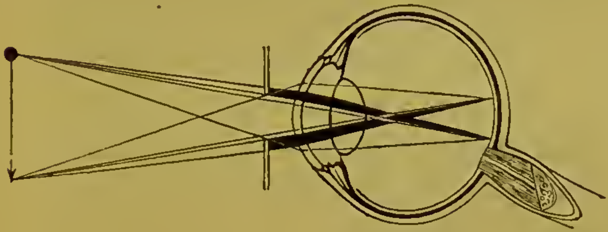
There being, however, as above seen, a dioptric apparatus in the eyeball, a well-defined and well-illuminated picture is projected on the retina, as shown in the diagram at page 26; or, as may be actually demonstrated by taking the eye of an animal newly slaughtered, such as an ox or a sheep, and cutting away a piece of the sclerotic and choroid coats at its back part, when by directing the cornea towards any object, a lighted candle for instance, we shall see a small inverted picture of the object shining through on the exposed retina like the image on the screen of the phantasmagoria. A similar demonstration may be given on a white rabbit's eye, without other preparation than dissecting clean the posterior surface of the sclerotica.

Like the lens of a camera obscura, the ocular dioptric apparatus so bends or refracts the rays of light, which enter the eye in a state of divergence from the several points of an external object, that they are made to converge to points or foci. These points or foci of light impinge on the retina, as on the table of a camera obscura, in the same relative order as that in which the rays forming them originally diverged from the several points of the external object; no one point of the retina being impressed at the same time by rays from more than one point of the external object.

As to the particular action of the dioptric parts of the eye on the rays of light in their course to the retina:—of the pencils of rays diverging from the various points of external objects, those only which fall on the cornea and are transmitted by it to the aqueous humour and thence through the pupil to the retina, are concerned in vision. Those rays which fall on and pass through the circumferential part of the cornea, are stopped by the iris, and are either reflected or absorbed by it. The effect of the refraction by the cornea, and of that by the different humours on the rays, is to make them converge; hence each pencil represents two cones, with their bases touching each other at the anterior surface of the cornea.

Of all the dioptric parts of the eye, the cornea is that which contributes most to the convergence of the rays of light. This is because the rays enter it from the air, which is of so much less refractive density than the cornea. The crystalline lens, though double-convex, and of greater refractive density than the cornea, contributes comparatively little to the convergence of the rays of light, because the latter enter the crystalline lens from the aqueous humour, the refractive density of which is not so much exceeded by that of the crystalline as the refractive density of air is by that of the cornea. The aqueous humour being somewhat less dense than the cornea, and presenting a convex surface to the incident rays, the convergence which the rays acquired in passing through the cornea is slightly diminished on entering it. The vitreous humour, on the contrary, continues and slightly augments the convergence of the rays which enter it from the crystalline lens, as it is of less density than that body, and presents a concave surface to the incident rays.

Attention has already been called to the optically advantageous position of the iris with its pupil in the eye. From a comparison of the annexed diagram with that at page 26, it will be seen that in consequence of the great amount of convergence which the rays undergo in passing through the cornea, a greater number of them are transmitted through the pupil, the iris being

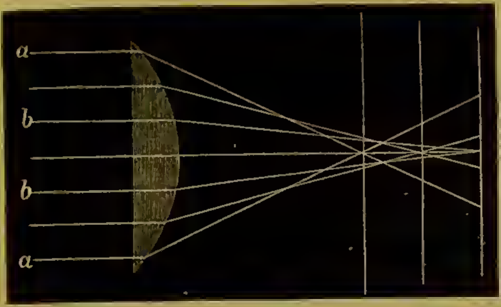


situated as it is, than would have been transmitted, had the iris with its pupil been placed in front of the cornea; whilst its purpose of a diaphragm, viz. obviating spherical aberration by excluding the circumferential rays, is also more effectually served.

We have thus seen that in regard to its construction and performance generally, the eye is a camera obscura, most admirably contrived with reference to the conditions under which it is called into use. Descending now from the consideration of its construction and performance generally, to its construction and performance in particular, we find provision made to obviate the optical aberrations, in the correction of which, in their instruments, opticians have expended so much pains and ingenuity. The provisions referred to, so far as they have been yet fully understood, are some of them inimitable by human art, and all are calculated to excite in every thinking mind renewed admiration of the transcendant wisdom and beneficence of the Almighty Artificer.

§ *Of spherical aberration.*

The curvature of the lenses employed in optical instruments is spherical, that being the only form which can be given to them by grinding with the requisite degree of truth. But convergent lenses with spherical curvatures have the defect of not bringing all the rays of light which pass through them to one and the same focus. Each circle of rays from the axis of the lens to its circumference has a different focus, thus:—



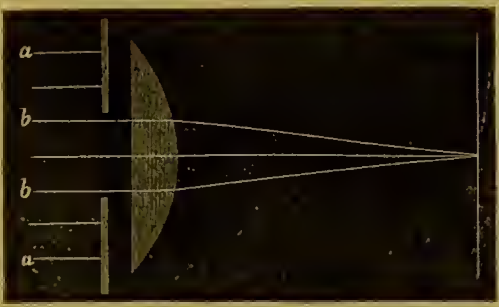
The rays *a a* which pass through the lens near its circumference, it is seen, come to a focus at a shorter distance behind it than the rays *b b*, which pass through near its centre. In other words, the rays of light *a a*, which pass through the lens near its circumference, are more refracted, whilst those *b b*, which pass through it near its axis, are less refracted.

The consequence of this defect of lenses with spherical curvatures, which is called *Spherical aberration*, is, that a well-defined picture is not formed by them in the camera obscura; for when the table is placed in the focus of the circumferential rays, the picture there projected is rendered indistinct by the halo produced by the central rays falling in a circle of dissipation, on the table at the same place, before they have come to a focus. On the other hand, when the table is placed in the focus of the central rays, the picture formed by them is rendered indistinct by the halo produced by the circumferential rays, which, having already come to a focus and crossed, now fall in a state of divergence on the table, forming a circle of dissipation.

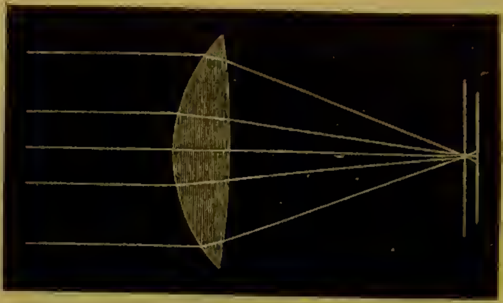
Lenses with elliptical or hyperbolical surfaces would be free from the defect just described, because presenting less convexity from their axis towards their circumference than lenses with spherical surfaces, the circumferential rays would strike less obliquely, and therefore be less refracted in proportion to the central ones.

But as elliptical or hyperbolical surfaces cannot be given to glass lenses with the requisite degree of truth by grinding, opticians have fallen upon other plans of diminishing or correcting spherical aberration in their instruments:—

1st. The grosser effects of spherical aberration are corrected by cutting off the passage of the rays *a a* through the circumference of the lens by means of a stop or diaphragm, so that the central rays *b b* only are concerned in the formation of the picture, thus:—



2ndly. Spherical aberration, not so much connected with the focal length of the lens as depending on the relative convexity of its surfaces, is much reduced by observing a certain ratio between the radii of its anterior and posterior surfaces; thus the spherical aberration of a lens, the radius of one surface of which is six or seven times greater than that of the other, is very much less when its more convex surface is turned forwards to receive parallel rays than when its less convex surface is turned forwards.



3rdly. Spherical aberration is still more reduced or altogether corrected by certain combinations of lenses. In *aplanatic* lenses, spherical is corrected along with chromatic aberration, by combining a convex lens of crown glass and a concave lens of flint glass. The spherical aberration of the convex lens of crown glass being reduced by the observance of the above-mentioned ratio between the radii of its anterior and posterior surfaces, what remains is corrected by the contrary spherical aberration of the concave lens of flint glass, without the convergent action of the convex lens being at the same time altogether neutralized.

As we can see objects at certain distances with perfect distinctness, and as a well-defined picture on the retina is a necessary condition for this, the dioptric parts of the eye must be free from spherical aberration. The wisdom to conceive, and the power to execute, thus displayed, may, in some measure, be illustrated by calling to mind, that it has been only by the exercise of the highest powers of human intellect and mechanical ingenuity, that the art of constructing dioptric instruments, free from spherical aberration, has been attained. The benevolence, on the other hand, that endowed us with eyes, in this respect so perfect, may be conceived, if we reflect on the advantage and pleasure we derive from the distinctness of our vision.

Great as is the excellence of the end attained, of preventing spherical aberration in the eye, equally great is the excellence of the means by which that end is brought about. Three principal means are found to be adopted:—

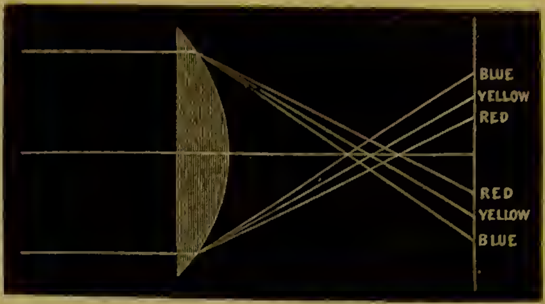
1st. The surfaces of the dioptric parts of the eye are not spherical, but those of the cornea and posterior surface of the crystalline lens are hyperbolical, and that of the anterior surface of the lens, elliptical—configurations found by theory fitted to prevent spherical aberration. This discovery was made at a time when it was not known but that the dioptric parts of the eye had spherical surfaces.

2nd and 3rd. But, as if the surfaces of the dioptric parts of the eye were not sufficiently removed from the spherical to obviate all aberration, we find other two contrivances in this organ which are fitted, the one to diminish, and the other to obviate, the aberration even of spherically curved lenses. The provisions referred to are: 1st. The stop or diaphragm, to cut off the circumferential rays, which we have in the iris with its pupil; 2nd. The diminishing density of the crystalline lens from its centre to its periphery, whereby the cirumferential rays are less refracted than they would have been by a homogeneous lens with similar surfaces. This elegantly simple contrivance has been hitherto inimitable by human art.

§ *Of Chromatic Aberration.*

If we examine closely the image projected on the table of a camera obscura provided with a common lens, we see that it is bordered with the colours of the rainbow; or, if we look through a common magnifying-glass at the letters on the title-page of a book, we see them coloured at their edges in the same manner.

The cause of the iridescent borders is that the primitive rays—red, yellow, and blue—of which a colourless ray of light is composed, are not all equally refrangible. Hence they are not all brought to one focus, but the blue rays being the most refrangible, come to a focus nearer the lens than the yellow ones, which are less refrangible, and the yellow rays than the red, which are the least refrangible, thus :—



Chromatic aberration proves still more detrimental to the distinct definition of images formed by a lens, than spherical aberration. This is, however, not so much from the iridescence of the borders of the picture, as from the size of the circles of dissipation which in the picture represent the points in the object. The principal defect arising from chromatic aberration is thus analogous to that from spherical aberration.

Chromatic aberration may still exist, although the spherical aberration of the lens be reduced to a minimum, or altogether corrected. In such a case, however, the effects of chromatic aberration are much diminished.

Chromatic aberration is corrected by combining, in the construction of lenses, two media of opposite form, and differing from each other in the proportion in which they respectively refract and disperse the rays of light; so that the one medium may, by equal and contrary dispersion, neutralise the dispersion caused by the other, without, at the same time, wholly neutralizing its refraction.

The media used for this purpose in the arts are crown glass and flint glass. The dispersive powers of the latter is much greater in proportion to its refractive power than that of crown glass; the dispersive power of flint glass being to that of crown glass as about 5 to 3, whilst its refractive power is only as 6 to 5. The combination of a convex lens of crown glass with a concave lens of flint glass of longer focus, will thus produce refraction without colour.

The discovery that the dispersive power of media is not in constant proportion to their refractive power, by leading to the construction of achromatic lenses was a gift from science to art of the highest value; and, as in the case of good gifts, manifold advantages have accrued to the giver.

It is a question, whether the human eye be free from chromatic aberration. As, under ordinary circumstances, objects are seen well defined and without any perceptible iridescent halo, it must be admitted that the eye is practically achromatic. And here we may observe, that it appears to have been in the belief that the eye is achromatic, and that its achromatism depends on its different dioptric parts having different dispersive and refractive powers, that Mr. Hall, the first maker of an achromatic combination, was led to his experiments; notwithstanding the discouraging, though fortunately erroneous, conclusion come to by Newton, that the dispersive and refractive powers of media are in constant proportion to each other, and that, therefore, the correction of chromatic aberration by any combination of media was hopeless.

Even if, under certain circumstances, we see objects with borders somewhat coloured, that does not indicate that chromatic aberration is not corrected in a great degree in the eye; for though lenses may still give some colour, they may be free from the worst part of chromatic aberration, viz., the large size of the circles of dissipation formed by the most luminous of the coloured rays; in other words, they may bring all the most luminous of the coloured rays to the same focus.

It may thus be said, that, for all practical purposes, the eye is free from chromatic aberration, and that in this, as in other respects, the wisdom, power and beneficence of its Maker are conspicuous.

It must, however, be admitted that the provision on which the achromatism depends has not been with certainty determined; but this is because we do not yet know the relative refractive and dispersive powers of the cornea and humours of the eye.

§ *Of Distantial Aberration.*

Though spherical and chromatic aberration be corrected, still another condition is necessary, in order that the picture of an object projected on the table of a camera obscura may be perfectly well defined; the table in all its parts must be at a due focal distance from the lens; and in order that it may be so, it must be concave, with an ellipsoidal, parabolical, or hyperbolical curvature.

But the focal distance from the lens varies according to the distance of the object; being nearer to, or more remote from, the principal focus of the lens, or its focus for parallel rays. Hence the distance between the lens of the camera obscura and the table requires to be adjusted according to the distance of the object. The more distant the object, the more the lens and the table require to be approximated, so that the latter may be nearer the principal focus of the former, and *vice versâ.*

If the lens and table were fixed at one

particular distance from each other, the rays of light from objects, at one particular distance only, would be collected, into exact foci on the table, and, consequently, a well-defined picture of such objects only would be projected on its surface. Rays of light from objects further from the camera than that particular distance, would come to foci before arriving at the table, and after having crossed, would fall on it in circles of dissipation. Rays from objects nearer the camera than the particular distance, would fall on the table before coming to foci, thus also forming circles of dissipation. And the result in both cases would be an ill-defined image.

The adjustment may be effected, either by moving the lens towards or from the table, the latter being fixed; or by moving the table towards or from the lens, this being stationary. Adjustment might be effected in a third manner, viz., the distance between the lens and table remaining unchanged, by substituting a lens of lower power when the picture of a distant object was to be projected on the table,—and a lens of higher power when the picture of near objects was to be projected on the table. A combination of all three plans, each in a less degree, would, of course, also effect the adjustment.

In the camera obscura of the eye we have the retina or table in its principal parts at a due focal distance behind the cornea and lens; it being spread out as a lining of the concave interior of the back part of the eyeball, on the one hand, and on the other, over the posterior and convex surface of the vitreous body, which fills up that concave interior. The curvature of the retina is not spherical, and though the fact has not been exactly determined, it is, probably, an arc of an ellipse, or of some other conic section.

The optical forethought and skill manifested in this conformation and disposition of the retina, will be more fully comprehended by calling to mind that opticians find it necessary to give to the table of their camera obscura a similar conformation and disposition; and by considering that, to use the words of an old but excellent writer on vision, "was the eye a cube, or of any multangular form, some parts of the *retina* would be too far off, and some too nigh, these refracting humours, and so could not but receive the several pencils of rays, some before they meet in the *focus*, and others after they meet, which would render the images of objects, and consequently vision, always confused and indistinct."

From what has been previously said in regard to the camera obscura, it is evident that if the distance between the different dioptric parts of the eye and the retina were fixed, and if the dioptric parts were incapable of change as regards their refractive power, objects could be seen perfectly distinctly only when viewed at one particular distance, as the rays of light forming the picture would come to exact foci only under such circumstances. But we know by experience that we can see objects perfectly distinctly at different distances within certain limits. Hence there must be in the eye some provision for its adjustment to different distances, as in our optical instruments. The particular nature of the provision, however, has not been ascertained with certainty by physiologists.

The mode in which it is considered most probable the eye is adjusted for vision at different distances is, by a change in the position of the lens—perhaps also a change of its form. By a slight movement of the lens forwards, with a slight increase of its convexity, rays of light from near objects could be brought to foci on the retina; whilst, for bringing the rays from distant objects to foci on the retina, a cessation of these changes, or opposite ones in a slight degree, would suffice. And to effect these changes we have mechanism enough, if we could fully understand it, in the ciliary body which forms the anterior part of the choroid coat, and which, by the ciliary processes, is dove-tailed with the corresponding processes of the ciliary zone—a peculiar construction which the hyaloid membrane of the vitreous body presents all around the circumference of the fossa in which the lens is set.

Whatever be the mechanism by which the eye is adjusted for seeing objects distinctly at different distances, it cannot but be of the most perfect nature to effect the purpose for which it was designed so completely as we all know by experience it does. In this excellence of the end attained, we recognise a manifestation of almighty wisdom; and not less of beneficence also, for without the power of adjustment, the advantages which we derive from vision would have been much circumscribed.

Though, for want of more accurate knowledge, we can thus only admire the excellence of the means as indicated by the perfection of the end, there are certain changes concomitant with the adjustment of the eye sufficiently patent to our observation, viz., changes of the size of the pupil, and variations in the direction of the axes of the eyeballs. These changes, however, are not essential conditions for the adjustment, though they are auxiliary; contraction of the pupils, and convergence of the axes of the eyeballs accompanying the adjustment for near vision, expansion of the pupils and parallelism of the axes, when the objects viewed are remote. In the exact concurrence of these acts, without any care or consciousness on our parts, the excellence of divine contrivance shines forth.

SECTION II.

Of the vital action of the Optic Nervous Apparatus, and its adaptation to the physical constitution of the eye.

Having contemplated the exquisite manifestations of divine wisdom and beneficence in the construction of the camera obscura of the eye, and the application of that instrument to project pictures of external objects on the retina, we have now to turn our attention to the wonderful result of the impression thereby made, viz., the *act of seeing.*

The act of seeing consists in the mind's perceiving impressions made on the retina by the light entering the eye from external objects. The sensations of vision depend wholly on the living actions and endowments of the optic nervous apparatus, and the co-operation of the mind through its organ the brain. When the optic nervous apparatus is paralysed it is no longer susceptible to the impression of light; hence, though every other part of the eye performs its function, there is blindness,—the camera obscura in vain throws the picture on the insensible retina.

As the rays of light from the several points of external objects fall, when the optical part of the eye is duly adjusted, as above explained, in so many distinct points on the retina, there are necessarily as many separate impressions made, but in consequence of their minuteness, the mind perceives them only in an aggregate sensation. According to the form of the whole extent of the surface of the retina thus impressed, and according to the quality of the rays which make the impression, so are the form and colour of the image which the mind perceives.

The expression "mind's eye" is merely figurative. Literally speaking, we have no eye hidden in the brain, with which the mind views the picture on the retina, as we look, by means of our visible eye, on an external picture. It is not the picture on the retina, but the impression made by the rays of light, forming the picture, that the mind takes cognizance of. In illustration of this see what is above said at page 26.

§ *Of the outness of Visual Perceptions.*

In the exercise of the senses of touch, taste, and smelling, the mind refers its perceptions to the corresponding organ of sense on which the impression is actually made. It is different, however, in the case of hearing and vision; in the exercise of both these senses, the mind refers its perceptions to without and to some distance from the body—to the place, in short, where the objects are, and not to the organ of sense on which the impression is actually made. This faculty of referring auditory or visual sensations to without, and to some distance from the body—to the place where the objects are, and not to the surface of the expansion of the auditory nerve, or of the retina, on which the impression is actually made, is a most wise and beneficent provision; seeing that we take cognizance of external objects by the sense of hearing only through the medium of sonorous undulations, and by the sense of vision only through the medium of luminous undulations, proceeding from the objects.

In the exercise of vision, then, to recur to its special consideration, we refer the sensation to without, and to some distance from ourselves, taking no cognizance of the fact that the impression exciting the sensation is actually made on the retina, nor of the intervention of the impressing agent, light.

It has been a question, whether the perception of externality or outness, as it is called by philosophers, by means of vision, being independent of experience through the sense of touch, is not owing to an original connate law of the economy; or whether, as was maintained by Bishop Berkeley, and has been maintained by many distinguished metaphysicians since his time, the mind does not originally refer the visual sensation to the eye, as it does a tactile sensation to the point of the finger, and that it is only by experience through touch, that we learn to perceive the outness of visible objects.

However this may be is immaterial to our argument. In either case we have a manifestation of wise design and forethought:—Supposing it to be by experience, through touch, that we learn to perceive the outness of visible objects, the aptitude we should then be endowed with of acquiring the faculty so readily, would be as much a manifestation of wise and beneficent design on the part of the Almighty Creator, who implanted in us that aptitude, as if the faculty of perceiving the outness of visible objects had been dependent on a law to which He had originally subjected our minds.

I may, however, here assert my belief that our faculty of perceiving outness is truly dependent on an original connate law, to which our minds have been subjected by the Creator.

In support of the opinion that we do not originally perceive objects to be *out* from the body, but that the mind originally refers the visual sensation to the eye, as it does a tactile sensation to the point of the finger, and that it is only by experience, through touch, that we learn to perceive the outness of visible objects, the allegation of persons born blind, who have acquired sight by an operation on the eye, has been adduced. Some of these persons have alleged that when they first saw, they thought all things touched the eyes. But this, it could easily be shown, is merely loose figurative language. Even if the fact were, as stated, it would, if strictly examined, prove no support to the opinion, because it was merely the surface of the eye which was alleged to be the seat of the sensation, whereas it ought to have been the retina, and the person ought therefore to have supposed that objects not only touched, but were actually in, the eye. Furthermore, they ought to have supposed that the upper part of objects touched the lower part of the retina, and therefore were in the lower part of the eye, and *vice versâ*.

Much more trustworthy evidence of what is the fact is supplied us by infants and the young of the lower animals. An infant grasps at external objects. Young turtles and crocodiles, Sir Humphrey Davy tells us, hatched without care of parents, run to the water. The crocodile will bite at a stick, if presented to it, the moment it is hatched, and a chick, on emerging from the shell, will run and pick up a grain,—an act the animal would not likely perform if it referred the grain to the interior of its own eye, instead of to without, and to some distance from its body.

The difference between the senses of touch and vision, as to where the mind refers the sensation, is well illustrated by what we perceive when we press upon the eyeball. The tactile sensation which results from the pressure, we refer to the part of the conjunctiva pressed on; but the visual appearance we refer to without and to some distance from the eye, and not only so, but to the side opposite that where the retina is pressed.

In illustration of how, in consequence of an original connate property with which the Creator has endowed the optic nerve, the mind refers the sensation excited by impressions on the retina to without, and to some distance from the body, I would adduce the well-known fact, that persons who have had the misfortune to lose a limb, sometimes feel as if the lost organ were still in connexion with the body, and that some part of it, perhaps, is the seat of pains and itchings. This is an example of a tactile sensation excited by some impression on the remaining part of the nerve, branches of which had been distributed to the amputated limb;—a tactile sensation referred by the mind, not to any part of the existing body, but to without, and to some distance therefrom. It might thus be said, that the functional condition which has, in this case, been induced in the nerve of the amputated limb, is similar to that which appears natural to the optic nerve.

Dr. Porterfield, from whose excellent work on the Eye I have already had occasion to quote, describes in so very interesting a manner his own personal experience of such sensations after amputation, that I shall quote his words:—

"In the case of Amputations, the Person, after the Loss of his Limb, has the same Perception of Pain, Itching, &c., as before, and feels them as if they were in some Part of his Limb, though it has long ago been amputated, and removed from that Place where the Mind places the Sensation. Having had this Misfortune myself, I can the better vouch the Truth of this Fact from my own Experience; for I sometimes still feel Pains and Itchings, as if in my Toes, Heel, or Ancle, &c., though it be several Years since my Leg was taken off. Nay, these Itchings have sometimes been so strong and lively, that, in spite of all my Reason and Philosophy, I could scarce forbear attempting to scratch the Part, though I well knew there was nothing there in the Place where I felt the Itching. And, however strange this may appear to some, it is, nevertheless, no way miraculous or extraordinary, but very agreeable to the usual Course and Tenor of Nature; for though all our Sensations are Passions or Perceptions produced in the Mind itself, yet the Mind never considers them as such; but by an irresistible Law of our Nature, it is always made to refer them to something external, and at a Distance from the Mind; for it always considers them as belonging either to the Object, the Organs, or both, but never as belonging to the Mind itself, in which they truly are; and therefore, when the nervous Fibres in the Stump are affected in the same Manner as they used to be by Objects acting on their Extremities, in the Toes, Heel, or Ancle, the same Notice or Information must be carried to the Mind, and the Mind must have the same Sensation, and form the same Judgment concerning it, *viz.*, that it is at a Distance from it, as if in the Toes, Heel, or Ancle, though these have long ago been taken off and removed from that Place where the Mind places the Sensation.

"If this should prove hard to be conceived, it may be illustrated by what happens in the Sensation of Colours; for though the Colours we perceive are present with the Mind, and in the *Sensorium*, yet we judge them at a Distance from us, and in the Objects we look at; and it is not more difficult to conceive how Pain may be felt at a Distance from us, than how Colours are seen at a Distance from us." *

§ *Of Erect Vision, though retinal impressions are inverted.*

Seeing that, in conformity with the laws of light, the pictures of external objects projected on the retina by the dioptric apparatus in front of it, are necessarily inverted, the fact, that notwithstanding the inverted impression thus made on the retina, we do not see the objects inverted, is a manifestation of provident care to adapt vital endowments to physical conditions, equally admirable with that displayed in our perception of externality or outness.

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* A Treatise on the Eye,—The Manner and Phenomena of Vision. Vol. i. p. 364. Edinburgh, 1759.

Like outness of visual perceptions, erect vision, though retinal impressions are inverted, has been a vexed question with philosophers. It is maintained by some that we, in fact, do see objects inverted, but that as everything appears inverted equally, the relative posture of objects is preserved. Hence, it is said, we are not conscious of the inversion. But if this were the case, we ought, by parity of reason, to be equally unconscious of inversion in looking at the inverted picture on the table of a camera obscura, for all the objects in the picture being seen inverted equally, their relative postures are preserved. No custom or experience, however, ever enables us to behold objects erect if their pictures are projected erect on the retina, any more than that it enables us to behold objects inverted when their pictures are projected inverted on the retina.

If we really saw objects in the posture in which their pictures are projected on our retina, the sense of touch would be in contradiction with the sense of vision; for while touch told us an object was erect, vision would declare it to be inverted, relatively to our own body. And surely if this were so, we should be able, by analyzing our sensations, to discover the fact,—which, however, I apprehend no philosopher has done. Nay, it can be demonstrated directly by experiment, that whilst the mind perceives sensations excited in the sense of touch, erect as the impressions are made, it perceives sensations excited in the sense of vision, in a reverse order to the impression. Thus, to repeat the experiment above described at page 68, if we press on the eyeball through the upper eyelid, we perceive the tactile sensation excited in the skin and conjunctiva, *above*, but the visual sensation excited in the retina, *below*;—*below*, it is to be repeated, where, if the sensation had been excited by the impression of light, instead of mechanical pressure on the upper part of the retina, the object whence the light came would have been situated.

Our seeing objects upright as they are, notwithstanding the impression on the retina is inverted, we must conclude, is independent of all experience, but depends on an original connate law of the economy—the same law as that on which our visual perception of outness depends—*the law*, viz. of *visible direction*. In obedience to this law, the mind, in referring a sensation, excited by an impression on the retina, to without, and to some distance from the eye, does so in a direction more or less nearly perpendicular to the surface of the retina at the point where the impression is made,—in the direction, namely, of the axis rays* of the cones of light which make the impression, and this, although, on account of the oblique position of the object, the axis rays may not themselves fall on the retina. The mind, in short, refers its perceptions resulting from an impression on the retina:—if on its lower part, *outwards* and *upwards* to the object whence the rays making the impression come,—if on its upper part, *outwards* and *downwards*,—if on its temporal side, *outwards* and *towards the nose*,—if on its nasal side, *outwards* and *towards the temple.*

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* In the *direction* only of the axis rays, not exactly coincident with them; as the axis rays do not pass on to the retina unrefracted in perfectly straight lines—not even those which pass through the centre of the cornea, because the centre of the crystalline lens does not correspond with that of the cornea, being more to the nasal side of the eye.

Erect vision, though retinal impressions are inverted, appears to have proved difficult of comprehension, only from its not having been considered in conjunction with the faculty of referring visual perceptions to without, and to some distance from the eye. Had we had no such faculty, but had we, by virtue of an original connate law of the economy, referred our visual perceptions to the surface of the retina, as we refer our tactile perceptions to the surface of the skin, it would indeed have been difficult to conceive, why we do not see objects inverted. No anatomical arrangement of the fibres of the optic nerves would have solved the difficulty. It would not have been accounted for by supposing the fibrils of the optic nerve which terminate in the upper part of the retina to have their central ends in the lower part of the optic lobes, and *vice versâ*, and the fibrils which terminate in the outer part of the retina to have their central ends in the inner part of the optic lobes, and *vice versâ*; for it is not to the central ends of nerves that the mind in any case refers its sensations.

Though I have occupied so much space in arguing that we originally see objects upright as they exist, notwithstanding the impression on the retina is inverted, and that this depends on an original connate law of the economy, it is to be observed, that, even supposing this faculty of seeing objects upright was merely acquired by experience, as is maintained by some, our main argument would not be in the least weakened. The aptitude we should then be endowed with, of acquiring the faculty so early, that we do not remember the time when we first acquired it, or had need of acquiring it, and the fact that we could not now divest ourselves of it by any effort of the mind, must be admitted as an equal manifestation of the Creator's wisdom, power, and beneficence.

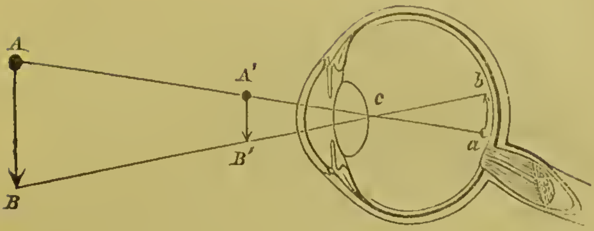
§ *Of the apparent size of Objects.*

Our eyeball is not quite one inch in diameter, and the retina, if spread out flat, would be only about one inch and three quarters. Yet, on this small extent of surface, the picture of a landscape, comprising miles of country, may be projected in miniature. The landscape, however, appears to the mind much greater than the extent of the retina impressed by its picture. The mind's visual perceptions, as regards size, are thus different from its tactile perceptions; for, to the mind, the size of an object observed by the sense of touch, corresponds to the extent of the surface of the skin impressed by it, and no more.

The greatness of the apparent size of visible objects, in proportion to the extent of the retina impressed by their pictures, depends on the projection outwards of the mind's perception of the picture. The size of the retinal picture being the same, the greater is the apparent size of the mind's picture, the farther distant out from the eye it appears projected. This is well illustrated by ocular spectra consequent to impressions on the retina. Thus, if after having, in the morning twilight, fixed our eyes on any object, we direct them to the sky, we shall see its spectrum projected of a gigantic size on the distant gray expanse. The same thing may be observed by a person troubled with *muscæ volitantes* before the eyes. If he looks on a light-coloured surface near him, he sees the *muscæ* projected on it of a small size; but if he directs the eyes to a more distant expanse, the white sky for example, he will see the *muscæ* projected on it of very much greater dimensions.

As in viewing an object, the eyes are adjusted to the distance at which it is situated, and the mind refers its perception outwards to that distance, it follows, from what has been above said, that the distance at which the object is situated, and the size of the picture it projects on the retina, are the conditions which determine its apparent size. As to the size of the picture on the retina itself, that depends upon, and is in proportion to the optic angle under which the object is seen.

It has been above shown, that the projection outwards of visual perceptions is in the direction of imaginary lines more or less nearly perpendicular to the surface of the retina at the various points impressed. These lines, named *lines of visible direction*, cross each other at a point in the interior of the eyeball a little in front of its centre, and behind the lens. Before and behind that point, the lines of course form angles by their intercrossing. Of these angles, that which is formed in front of the point of intersection, by the lines extending to the extreme points of the external object, is the optic or visual angle, thus :—



a A and *b* B lines of visible direction; *c* point of intersection; A *c* B optic or visual angle; *a c b* angle subtended by the image on the retina.

The angle subtended by the picture on the retina being equal to the optic angle, that picture is, as above said, of a size in direct proportion to that of the optic angle. The optic angle again is in direct proportion to the size and nearness of the object.

Though, the nearer the object is to the eye, its apparent size is greater, in consequence of the size of the picture on the retina (one of the conditions determining the apparent size of objects) being greater, it is to be remembered that the proposition above enunciated, viz., that the size of the retinal picture being the same, the size of the mind's picture is greater, the farther distant out from the eye it appears projected, still holds good;—the distance at which an object is situated (irrespective of its influence on the size of the optic angle, or, what is the same thing, the size of the retinal picture) being the other condition determining the apparent size of objects.

That the apparent size of an object depends not alone on the size of the angle under which it is viewed, in other words, on the size of the retinal picture, but also on the distance to which the eye requires to be adjusted to view the object, is proved by the fact, that objects of very different size, but situated at different distances, are seen under the same optical angle, and therefore impress by their picture the same extent of retina, and yet to the mind their size appears different. Thus, a pea, held up before the eye, is seen under an angle as great as the moon, and therefore throws a picture on the retina as large, and yet the apparent size of the moon is much greater than that of a pea. This is illustrated by the diagram at page 81, in which the object A′ B′ is seen under an angle as great as the object A B, and therefore throws a picture on the retina as large.

Along with the projection of the mind's pictures of objects outwards and in an erect position, their projection at the same time of a size greater than the extent of the retina impressed, comes under the law of visible direction, and is to be equally viewed as a provision by which the vital action of the optic nervous apparatus and the physical constitution of the eye are adapted to each other, and both to external circumstances,—a provision such as could be ordered only by divine wisdom and beneficence, and carried out by Almighty power.

SECTION III.

Of the Duration of Sensations after the impression on the retina has ceased.

Our visual sensations, in common with the sensations of our other senses, continue for a short space of time after the impression which excited them has ceased. On this depends, in the case of vision, the appearance of a ribbon of light when we wave a stick, burning at the end, rapidly before the eyes. The burning stick, on returning, makes a new impression on the retina before the sensation excited by the previous one has ceased, and so there is the appearance of continuity in the light.

In the retention of visual sensations, we have a wise and beneficent provision for facilitating the exercise of sight. It is owing to it, that we do not lose perception of an object in winking. In making a survey of the different objects in the field of vision, we successively direct the eye to them in such a manner that their images may be received on the middle of the retina, which is its most sensitive part. In thus moving the eye about, the perception of the object last looked at is retained, until the view is fixed on the next. Without the retention of visual sensations, reading would thus be an act not admitting of such ready performance as it does. We should require to keep the eye fixed on a word for a longer time, otherwise the mind would fail fully to perceive it; the mind requiring a certain length of time for its operations.

The time for which visual sensations are usually retained after the impression has ceased, has been estimated at about one-third of a second. In the absence of new and stronger impressions, however, sensations may be retained for a longer time. Hence, an image of an object may continue to be seen for some seconds after the eyes have been turned away from looking at it. This phenomenon is, in general, most readily observed in twilight; in daylight the impression of the object on the retina requires to have acted more intensely and a longer time to produce the effect. In certain morbid states of the retina, sensations are retained a much longer time than natural.

To persons not aware of the retention of sensations by the retina, their occurrence, when strongly marked, appears startling and mysterious, and has no doubt been the origin of many superstitious stories of visions and ghosts. In the twilight, a person, perhaps after having unconsciously rested his eyes on some dark object, such as a post, will, on looking towards the gray sky, see projected there a gigantic white image of the post. This, with a little assistance from the imagination, may be readily taken for a human figure dressed in white. Sensations being retained only for a short time after the impression has ceased, the supposed vision of a human figure dressed in white soon vanishes, as visions and ghosts are said to do.

If the object from which the impression has been derived is coloured, the spectrum or image is coloured also, but differently, thus: if the eye be fixed on a red-coloured object for some time, and then turned away from it, a spectrum of the object will be seen of a green colour. If, on the contrary, the object looked at be green, the spectrum will be red; again, if blue, the spectrum will be orange; if orange, the spectrum will be blue; if yellow, the spectrum will be violet; if violet, the spectrum will be yellow.

From this it is seen that the colour of the spectrum is always that which being added to the colour of the object looked at, makes up the sum of the three primitive colours—yellow, red, and blue, which by their combination form white light; hence, the name *complementary* which has been given to the colour of the spectrum.

Although we cannot search out and determine the reason why after-sensations of colour have been so ordered, we can still perceive from their regularity and constancy that they are not the result of chance, but of some wise design. The beneficence of the design we experience in the harmonization of colours.

SECTION IV.

Of the concurrent action of the Two Eyes.

§ *Single vision with Two Eyes.*

As the rays of light, emanating or reflected from the different points of a visible object, proceed in all directions and in straight lines, those from the same points must necessarily some of them enter the one eye and some the other, and so impress both retinæ in the same manner, and at the same time. From this double impression, it is to be observed, we have not a double perception of the object, but only a single one, provided the eyes be naturally directed, *i. e.* provided their optic axes intersect at some point of the object, provided their centres of revolution coincide, and provided their horizontal and vertical diameters are respectively parallel.

When the two eyes are thus naturally directed, the parts of the two retinæ which receive similar and simultaneous impressions from the rays of light entering them from a given point of the object, are their vertices and their various parts equally situated in relation to them, on the temporal half of one retina, and on the nasal half of the other. These parts of the two retinæ, as similar and simultaneous impressions on them yield but a single visual perception, are called *corresponding* or *identical parts.*

If the two eyes are not directed in the manner above described, the rays of light from given points of the object will not then fall on corresponding parts of the two retinæ, and the consequence will be that the two impressions will be perceived by the mind separately, and the object will be seen double.

Amidst the various movements of the eyeballs, the correspondence in their direction necessary for single vision is maintained by the concurrent action of their muscles. See next section in explanation.

The advantages which we derive in the exercise of vision from two eyes are—greater extent of our field of view, greater vividness of our visual sensations, real perception of the three dimensions of space, and the true position of objects within a certain distance. In the reconcilement of these advantages from two eyes, with single vision, we have, as in the cases of outness of visual perceptions, and erect vision though retinal impressions are inverted, an example of the adaptation of vital endowments and physical conditions to each other, of consummate excellence and wisdom. Had there been no such adaptation, but had the optic nerves been similarly endowed with the nerves of touch, we should not only have referred our visual sensations to the surface of the retina, and perceived them inverted, but also, when both retinæ were impressed, have had a double sensation.

Single vision with two eyes, in common with outness of visual perceptions, erect vision though retinal impressions are inverted, and greater apparent size of objects than the extent of the retina impressed, is considered to depend on the law of visible direction. By virtue of this law, the mind, in referring a sensation excited by an impression on the retina to without, and to some distance from the eye, does so in a direction depending on the part of the retina impressed. Now, when impressions are made on corresponding parts of the two retinæ, the two sensations resulting from the impressions, it is said, are referred by the mind outwards to the same place. The image seen by the one eye, thus coinciding with that seen by the other, the object appears single. This is in the main true, but single vision with two eyes depends on something more.

The mind does not perceive the sensations, excited in corresponding parts of the two retinæ, at the same instant of time, but only the one sometimes, and the other sometimes, or part of the one with part of the other. This is well shown when impressions, dissimilar in colour but of the same shape, are made on corresponding parts, *e. g.* a blue impression on the one retina, and a yellow one on the other. In this case, an admixture of the two colours is not seen, but either the blue alone or the yellow alone, at the same instant of time, or the blue in part and the yellow in part. If the impression on the one retina be much stronger than that on the other, the former predominates, or excludes the latter altogether from the mind's perception.

Furthermore, it has been shown by Mr. Wheatstone, that in viewing an object of three dimensions, while the optic axes converge, obviously dissimilar perspectives of it are projected on the two retinæ; the impressions are therefore not made exclusively on corresponding parts, and yet the mind does not perceive two superposed dissimilar images, but only a single one, though not exactly like either of the perspective pictures of the object projected on the retinæ, nor at the same place as the object would appear if one eye only were used.

This fact, which is beautifully demonstrated by Mr. Wheatstone's *stereoscope*, shows, that it is not an indispensable condition for single vision, that every part of the impressions on the two retinæ be made on corresponding points, nor that the images, as seen by either eye, be projected outwards to exactly the same place. Still, if the non-correspondence of the points of the two retinæ impressed were beyond certain limits, the projection outwards of the image, as seen by either eye, to different places, would also be beyond certain limits, and the result would be double vision.

In explanation of the remarkable fact demonstrated by Mr. Wheatstone's stereoscope, it is to be observed, that though the mind perceives separately, impressions on neighbouring non-corresponding points of the two retinæ, in the region of the vertex or most sensible part, at the same instant of time, it does not perceive separately, impressions on neighbouring non-corresponding points at the circumferential and less sensitive parts of the two retinæ; the degree of non-correspondence of the points impressed being, let it be observed, within certain limits.

In viewing an object of three dimensions with the optic axes convergent, "it is that part of the object at which the optic axes intersect, the image of which is projected on the middle parts of the two retinæ. Now, of the perspectives of the object which are projected on the two retinæ, this is the only part which is similar for the two eyes. It, therefore, falls on corresponding points, the condition necessary for a single visual perception, from an affection of the middle parts of the two retinæ. It is, on the contrary, those parts of the object out of the horopter,* the image of which, necessarily dissimilar for the two eyes, is projected on the circumferential parts of the retinæ—the very parts, affections of accurately corresponding points in which are not, as above seen, a necessary condition for a single visual perception."†

Like projection outwards and erect vision, single vision with two eyes has been a vexed question with philosophers. Instead of being dependent on an original connate endowment, by virtue of which, simultaneous impressions of certain parts only of the two retinæ yield to the mind but a single visual perception, some philosophers have maintained that single vision with two eyes is merely the result of custom.

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* An imaginary circle or rather sphere, the circumference of which cuts the point of intersection of the optic axes on the one hand, and the points of intersection of the lines of visible direction within the two eyes on the other.

† Principles and Practice of Ophthalmic Medicine and Surgery. By the Author, p. 380.

Supposing there was any doubt in the matter, it would be, as in the case of the analogous questions of projection outwards and erect vision, immaterial to our argument in which way the question were solved. For endowment with the aptitude to acquire by custom, and that with perfect certainty, the faculty of correcting an error of sight, would be an example of wise and beneficent design on the part of the Almighty, who conferred the endowment, as great as if he had imparted the faculty originally.

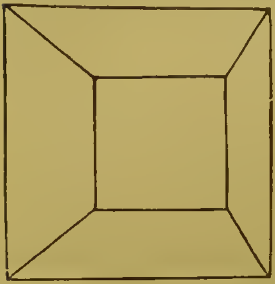
§ *Visual perception of the three dimensions of Space.*

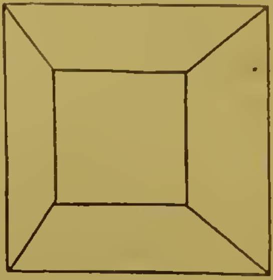
By the combined action of the two eyes we are enabled to perceive the three dimensions of objects. This is owing to the position of the two eyes, by which each is fitted to receive on its retina a different perspective of the object, in a manner analogous to that in which, with two fingers, we receive impressions from two sides of a solid body, so that we can recognise its thickness as well as its length and breadth, whilst the mind, in conformity with an original connate law of the economy, as above shown, does not perceive two superposed dissimilar images, but only a single one, and that, unlike either of the perspectives, in full relief or intaglio, as the case may be.

Our faculty of perceiving the three dimensions, length, breadth, and thickness, used to be attributed by philosophers solely to the touch; the perception of solidity by the eyes being, they supposed, acquired merely by experience through that sense.

It is quite true, that by the active exercise of touch—by moulding the hand around a solid body—we recognise its three dimensions. It is also quite true, that using one eye only in vision, though we can, from certain appearances, infer that an object presents length, breadth, and thickness, the appearances referred to can be represented by painting on a plain surface, and therefore the judgment by vision with one eye as to the three dimensions cannot be depended on. But, on the other hand, it is quite true, and this is to be particularly remarked, that though by moulding the hand around a solid body, we can recognise its three dimensions, we cannot by simple touch, *i. e.* contact of a body with the skin, recognise any more than the two dimensions of length and breadth. Again, it is also quite true, that though by means of one eye, we can recognise truly length and breadth only, we can, if we look with the two eyes at a solid body near us, perceive its three dimensions of length, breadth, and thickness, as certainly and demonstrably as we can by the touch when moulding the hand around the object. Mr. Wheatstone's stereoscopic demonstrations satisfactorily establish this important fact.

In the absence of a stereoscope, the fact may be sufficiently well demonstrated by viewing the subjoined figures, — the dissimilar perspectives of a truncated four-sided pyramid, as follows:—





Fixing the right eye on the right hand figure, and the left eye on the left hand figure, hold between the eyes in front of the nose the board of a book. The two figures will then be seen to approximate, and run into one, so as to represent, in bold relief, the skeleton of a truncated four-sided pyramid.

The stereoscope, I may here observe, shows how vain it is for a painter to attempt to represent objects in full relief or intaglio, as seen with the two eyes. All that can be really and naturally represented by painting, on a plain surface, is merely the *appearance* of relief or intaglio as seen when one eye only is used. This explains why it is, that, in looking at pictures, we see them to greater advantage when one eye is closed; in fact, when we use both eyes, the illusion of relief, even as seen with one eye, is in a great measure destroyed.

The faculty of perceiving the three dimensions by the two eyes, implies the faculty of recognising the distance and position of near objects by the same means. On the other hand, as we cannot, with a single eye, recognise the third dimension, so we cannot, with a similar limitation of sight, accurately pour wine into a glass, snuff a candle, or perform the like operation.

SECTION V.

Of the movements of the eyeballs.

Of a globular form, each eyeball lies safely lodged in its socket, where it is so balanced in the orbital capsule, as to admit of being turned in all directions, within certain limits, by the action of its six muscles. These muscles acting singly, make it revolve in so many different primary directions on three imaginary axes ; but acting in various combinations, they make it revolve, on other axes, in various other directions.

The axes on which the eyeball is thus made to turn, pass through a certain ideal point in its interior—the point of intersection of the lines of direction—the situation of which in the orbit or socket always remains the same. Each axis is at right angles with the direction in which the force or muscle acts. From this, therefore, the direction of the axis may be determined. Thus, the axis on which the internal and external straight muscles make the eyeball revolve, is vertical; that on which the superior and inferior straight muscles make it revolve, is horizontal and extends from the one side of the eyeball to the other—from a point a little farther forwards on the nasal side, to one a little farther backwards on the temporal side, than if it had passed through the eyeball in a direction at right angles to the optic axis; that on which the oblique muscles make the eyeball revolve, is also horizontal, and extends from near the temporal edge of the cornea obliquely backwards to a point near the entrance of the optic nerve into the eyeball on the nasal side.

When muscles act in combination, the direction of their force and that of the axis, on which this force makes the eyeball revolve, are found from the construction of the parallelogram of forces, and the parallelogram of forces is derived from the direction of the optic axis, and the known direction of the individual muscles.

" The forces acting on a globe with three axes, on which it revolves in the direction of the three dimensions of space, rotate it most easily, when all the three axes intersect each other at right angles. This, however, is not the case in the human eye, for the axis of the oblique muscles intersects that of the superior and inferior straight muscles at an angle of 35°, because the tendons of the superior and of the inferior oblique muscles form an angle of 55° with the optic axis. Had the axis of the oblique muscles cut that of the superior and inferior straight muscles at right angles, then the tendons of the oblique muscles must have also intersected the optic axis nearly at right angles. In this case, however, the pulley of the superior oblique and the origin of the inferior oblique muscles must have been farther back in the orbit, but then the action of the muscles would have been too weak, unless the muscles had been much thicker, though even then their strength would not have been sufficient." *

The two eyeballs move in concert, and in order to this, their different muscles act in various combinations, sometimes as associates, sometimes as antagonists, according to the manner in which the eyeballs require to be directed, so that their axes may meet at the object looked at, their centres of revolution coincide, and their vertical and horizontal diameters be parallel—conditions necessary for the simultaneous projection of the images of objects on the corresponding parts of the two retinæ.

We have already seen that it is the middle

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* Ruete, Lehrbuch der Ophthalmologie.

region of the retina which is the most sensitive part, and that it is, therefore, only from impressions on it, that we derive very lively visual perceptions. This being the case, it is evident that we can take in distinctly at one glance but a very small part of a view before us. By the rapid and varied movements of the eye, however, we can, as above explained, rapidly survey the whole field of vision by a series of successive glances. Had the eyeball been incapable of motion, we must have had to turn the whole head about, in order to see more than the very small part of the field which can be vividly perceived at one glance. This, it need scarcely be remarked, would have been very inconvenient. Besides, in consequence of the comparative slowness of the movements of the whole head, the impression of what was seen at one glance would not have been retained with sufficient vividness until the next, and so there would have been little or no continuity in the view before us.

Moreover, with two eyes incapable of

motion, we could have seen objects single at one particular distance only, viz. the point of intersection of the two fixed optic axes.

SECTION VI.

Of the provisions made for the protection of the Eyeballs.

In contemplating a modern achromatic telescope or microscope, we find reason to admire the instrument not only for the excellent manner in which it serves its main purpose, and for beauty of workmanship, but also for the various ingenious though secondary provisions made for its convenient management, and preservation from injury. As attention is thus wisely and carefully directed by the optician to the management and conservation of his well-contrived and beautifully finished-off instruments, so provision has been made for the management and protection of the eyeballs, evincing wisdom and beneficence, not greater indeed than we have seen displayed in the construction and endowments of these organs, but perhaps more readily perceived and understood.

At the same time that the eyeballs are so placed in the head and moved, that they may be directed to the various objects in the field of view, they are securely protected from any ordinary external violence. The prominent border of the orbit or socket all round, and especially above where the eyebrows are, is ever ready, like a bulwark, to bear the brunt of a blow, whilst the eyelids, bordered with the eyelashes as with a palisade, are immediately closed, even without an effort of our will, against the intrusion of extraneous particles. And if, as sometimes happens, foreign particles do, notwithstanding, get into the eye, more especially such subtle particles as dust, acrid vapours, and the like, a flush of tears from the ducts of the lacrymal gland takes place which washes away the offending agent.

Against the entrance of too strong light also, the eyebrows, eyelids, and eyelashes are ever a ready barrier.

In the waking state, the eyelids are open, except that every now and then they are momentarily closed in the act of winking. The upper eyelid is kept raised by a muscle for the purpose (the levator), whilst the lower eyelid is held down by its own elasticity and that of the cheek. There is a proper muscle for closing the eyelids, namely, the orbicular. The action of the levator muscle of the upper eyelid being suspended in sleep, it is by the unrestrained action of the orbicular muscle that the eyelids are kept closed. It is also by the momentary action of the same muscle every now and then, that winking is caused; overcoming the action of the levator muscle of the upper eyelid and the elasticity of the lower, it draws down the upper eyelid and raises the lower considerably.

Winking, which is simultaneous in both eyes, serves the purpose of wiping the front of the eyeball, of spreading the tears over the surfaces of the conjunctiva, relieving the front of the eyeball from prolonged exposure to the air, and giving the retina intervals of rest from the action of the light. The retention of sensations by the retina, so that winking does not interfere with sight, has been referred to as a wise and beneficent provision.

For the lubrication and protection of the delicate and sensitive borders of the eyelids, an unctuous matter is poured out on their surface by the minute mouths of the ducts of the meibomian glands. These mouths may be seen on close inspection of the surface of the broad borders of the eyelids, arranged in a row all along.

The source of the tears is the lacrymal gland, which is situated above and to the outer side of the eyeball, securely lodged in a pit behind the edge of the socket. When the tears are poured out in unusual quantity, as they are in certain affections of the mind, and in consequence of irritation of the eye from the intrusion of foreign particles or the like, they run over the margin of the lower eyelid and drop down the cheek. A flow of tears in a less degree is, however, constantly taking place, by which the transparent front of the eyeball and the surfaces of the conjunctiva in general are washed and maintained in a moist state. The direction in which the tears flow over the surfaces mentioned, is from above and near the outer corner of the eye, where the ducts of the lacrymal gland open and discharge them, downwards to the inner corner, whence, as they accumulate, they are drawn off into the nose by the derivative lacrymal passages.

At the termination of the firm border of each eyelid towards the inner corner, there is a slightly prominent papilla, with a small orifice at its point. These papillæ are directed towards the pit or depression (lacrymal lake) at the inner corner, where the tears accumulate. By the two orifices which lead each into a small duct or canal, the tears are absorbed, and by the ducts are conveyed into the lacrymal sac, which lies concealed under the skin, in a particular groove of the orbit, at the inner corner of the eye. From the lacrymal sac, the tears pass, by the nasal duct, into the nose.

The wise forethought and beneficence, which planned the mechanism, by which the eyelids are moved and the tears drained away into the nose, are perhaps most strikingly illustrated when the mechanism is anywise disturbed by disease. Thus the levator muscle of the upper eyelid is sometimes paralysed, in which case the upper eyelid hangs down over the eye, in consequence of the unrestrained action of the orbicular muscle. Again, the orbicular muscle may be paralysed, in which case the eyelids cannot be closed, the upper being kept elevated by its levator muscle, and the lower depressed by its own elasticity and that of the cheek. Then as to the draining away of the tears into the nose, this may be prevented by obstruction of the lacrymal passages; or by the tears not being absorbed by the lacrymal points, owing to the papillæ being no longer duly directed to the lacrymal lake, in consequence of paralysis of the orbicular muscle.

CHAPTER IV.

OF THE SENSE OF VISION IN THE LOWER ANIMALS.

> And God created great whales, and every living creature that moveth, which the waters brought forth abundantly, after their kind, and every winged fowl after his kind: and God saw that *it was* good.
>
> And God made the beast of the earth after his kind, and cattle after their kind, and every thing that creepeth upon the earth after his kind: and God saw that *it was* good. —Genesis i. 21 and 25.

Thus took place the creation of fish and fowl, of beast and cattle, and of every thing that creepeth upon the earth after his kind, and thus with approbation did God look upon the accomplished work. In this regard of approbation, the sense of vision, in such animals as He had seen fit to endow with it after their kind, was, let it be reverently observed, of course included. And truly the sense of vision is *very good*, whether we examine it in the lower animals or in man. In the human eye, indeed, "that masterpiece of divine mechanism" which we have been considering in the preceding pages, it might almost have been supposed that skill in optics had been exhausted. In the review, however, we are now about to take of the sense of vision in the lower animals, we shall find no abatement of such skill. On the contrary, in the modifications of the optical apparatus by which the eyes are adapted to the peculiarities of *habitat* and mode of life of animals after their kind, we shall discover new manifestations of skill in optics, and that exercised in the most beneficent manner.

SECTION I.

Of the optical structure and mode of action of the eyes of the lower animals.

The eyes of all the vertebrate animals, and of many of the invertebrate also, are constructed on the same optical principle as that we have above studied in the human eye, viz. the principle of the camera obscura, with dioptric parts for collecting the divergent rays to foci. The eyes of certain others of the invertebrate animals, viz. insects and crustaceans, are, for the most part, constructed on a principle altogether different, that, namely, of receiving the central rays of the cones of light, from the different points of the field of view, by so many different eyelets, arranged together in the direction of the radii of a common sphere, and excluding the divergent rays of the cones, instead of making use of them by collecting them into a focus.

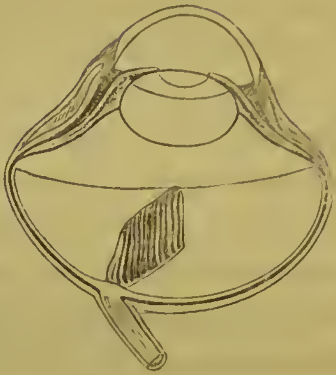
Eyes constructed on the latter plan do

not require any adjustment for different distances, nor any modification of the form of their dioptric parts according to the medium —air or water—in which the animal lives. Eyes constructed on the former plan, on the contrary, require not only adjustment for different distances, as we have already seen, but also, as we are now about to show, modifications of the form of the dioptric parts to adapt them to the medium in which the animal lives.

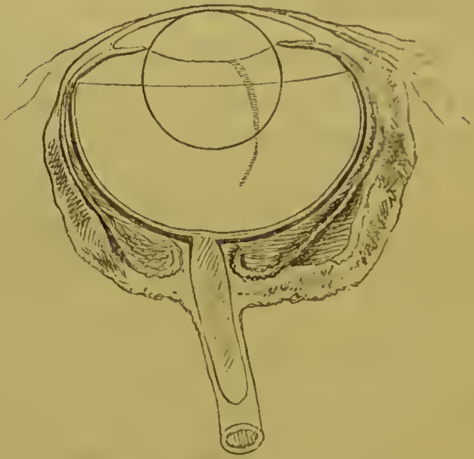
A comparison of the eyes of birds and fishes will demonstrate the provident care which the Almighty Creator has taken to meet this requirement.

§ *Comparison of the eyes of Birds and Fishes.*

The eyeball of birds has a very convex cornea, a large quantity of aqueous humour, and a crystalline lens of medium convexity; whilst that of fishes has a flat cornea, a small quantity of aqueous humour, and a spherical crystalline, which projects



Horizontal Section of the Eye of the Golden Eagle.*



Horizontal Section of the Eye of the Cod.*

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* From Soemmerring's Horizontal Sections of the Eye.

through the pupil into the anterior chamber,—as far forwards, in the cod, as to be in contact with the posterior surface of the flat cornea. (See annexed figures.)

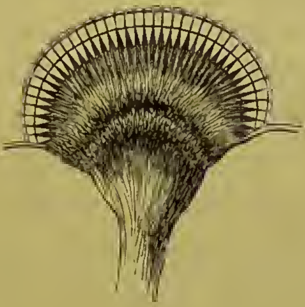
The rays of light entering the eye of birds from the thin air, are necessarily much refracted by the dense and very convex cornea. In order, however, that birds may not, in consequence of this, be short-sighted, but that they may be able to see distant objects, as their mode of life requires, the lens is not so convex, or so dense, as to add very much to the convergence the rays have already undergone, in passing through the prominent cornea and aqueous humour, whilst the retina is expanded at such a distance behind the lens as to correspond with the focus of the dioptric parts in front.

The design of the flat cornea of the fish's eye will be evident, when it is remembered that the refractive density of water, and that of the cornea and aqueous humour, are but little different. A convex cornea, with a large quantity of aqueous humour in the eye of the fish, therefore, would have contributed little or nothing towards bringing the rays of light to foci; but to make up for this, the crystalline lens, which is of greater refractive density than water is, as has been already said, spherical, whilst to receive the foci to which the rays are speedily brought by its powerful action, the retina is expanded at a sufficiently short distance behind.

Amongst the invertebrate animals, cuttlefishes have eyes much resembling those of proper fishes, but the cornea is actually wanting or reduced to a mere circumferential ring, and through the opening, thus left, the crystalline, which is of a spherical or rather elliptical form, projects. The representative of the vitreous humour is a fluid, and as the rays of light must, in consequence of this, be still more quickly brought to foci by the powerful action of the crystalline, the axis of the posterior segment of the eyeball is very short.

§ *Of the compound eyes of Insects and Crustaceans.*

The optical apparatus of the compound eyes of insects and crustaceans, consists of some thousands of small transparent conical bodies, the apices of which are sunk in a thick layer of pigment, whilst their closely arranged bases, directed outwards, form a tessellated convex surface, which is covered by a thick transparent membrane, serving the purpose of a common cornea. In most insects and tenfooted crustaceans, the corneal membrane presents facets correspond-



Section of the compound eye of an insect, magnified.

ing each to the base of a transparent cone. In some crustaceans, a lenticular body is interposed between the corneal facet and the base of the cone.

At the bottom of the eye the optic nerve swells out, and separates into fibrils, which proceed divergingly through the layer of pigment to the apex of each of the transparent cones.

The mode in which the light is transmitted by the dioptric apparatus, just described, to the fibrils of the optic nerve is as follows: Of the rays of light, from a given point of an object, which fall on the convex surface of the compound eye, in a state of divergence, some only strike the base of one of the transparent cones perpendicularly. These rays alone are transmitted by that cone to the fibrils of the optic nerve with which its apex is in connexion, and form an image of the point of the external object whence the rays proceeded. The other rays, falling obliquely on the surface of the eye, are not transmitted to the optic nerve, but are either reflected, or, passing obliquely through the cones, are absorbed by the pigment interposed between their sides, and so are not concerned in the production of the image.

A repetition of the process, now described, by each of the innumerable eyelets of which a compound eye is made up, will give a picture of a corresponding number of points of the external object whence the rays come. It thus results, that the whole picture projected on the retina or extremities of the optic nervous fibrils, by this mechanism, will resemble a piece of mosaic work. And, as remarked by Professor Müller, of Berlin, who was the first to explain this beautiful optical contrivance, a better idea cannot be conceived of the image of external objects projected on the retina of compound eyes, than by comparing it to a fine piece of mosaic work.

In the eyes above referred to, in which a lenticular body is interposed between the corneal facet and the base of the transparent cone, not only are the central rays of the cone of light, which fall perpendicularly on the surface of the facet, transmitted to the optic nerve, but also some of the divergent ones; these being so refracted by the lenticular body as to be rendered convergent.

A blending of the two plans of dioptric apparatus—that by which the divergent rays of light are brought to a focus, and that by which they are excluded—may here be perceived. Indeed, each of the numerous eyelets of a compound eye with lenticular bodies, is composed of dioptric elements, homologous with those of simple eyes, or eyes constructed on the principle of the camera obscura, thus:—the transparent cone in front of the fibril of the optic nerve corresponds to the vitreous humour,—the lenticular body interposed between the base of the cone and the corneal facet to the crystalline lens,—and the corneal facet to the cornea. An anatomical link, between compound eyes and simple eyes, is presented in the aggregates of simple eyes of certain myriapods and crustaceans.*

From the account above given of vision

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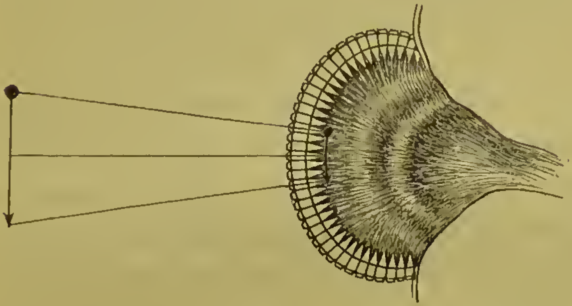
* Müller's Physiology, vol. ii. p. 1117.

with compound eyes, it is evident that the images projected on the retina must be erect, and not inverted, as in the case of simple eyes, thus:—



Notwithstanding this result, it is also evident that if, as there is reason to suppose, projection outwards of the visual perceptions of the animal be in the direction of the rays of light, which impinge on the retina, objects will be seen erect.

SECTION II.

Of the provisions for the protection of the eyes in the lower animals.

Speaking generally, it may be said, that, amongst vertebrate animals, the terrestrial have well developed eyelids, whilst the aquatic have them imperfectly developed,—the eyes of animals inhabiting the waters not being exposed to the same injurious influences, as those of animals living in the air.

Of all the provisions for the protection of the eyes, met with among the lower animals, that which perhaps offers the most striking exemplification of the Creator's wisdom and beneficence is the nictitating membrane or third eyelid.

In man and quadrumanous animals, there is, at the inner corner of the eye, a small semi-lunar fold of the conjunctival membrane. In quadrupeds, the corresponding structure is developed into a large membraniform organ, — known, in general, by the name of nictitating or winking membrane, and, in the horse, by the name of the *haw*, —which admits of being rapidly moved, from the inner towards the outer corner, over the front of the eye and again retracted. This organ evidently serves the purpose of more effectually cleansing the surface of the eyeball. In birds, again, the corresponding organ is still more highly developed, and forms in them what is called the *third eyelid*. In the tortoise and lizard tribe, among reptiles, a third eyelid also exists, but not so highly developed as in birds.

The third eyelid of birds " is transparent and capable of covering the whole front of the eyeball. Enclosed in the conjunctival reduplication, there is a fibro-cartilaginous structure, very thin and membranous. Of a triangular form, the third eyelid has its free margin oblique from above downwards, and from without inwards. In the state of repose, it is retracted and folded vertically in the nasal angle of the eye. The third eyelid is drawn over the front of the eye by a very peculiar mechanism, consisting of two muscles, the slender tendon of one of which runs through an elongated loop in the broad free end of the other." *

"From this curious disposition of the muscles," says Dr. Porterfield, "it is easy to conceive, how this internal eyelid is extended over the cornea far enough to cover all the pupil, though the muscles themselves are contained in a small space. Every body knows, that the contraction of all muscles is only in a certain given proportion to their length; and, therefore, that the eyelid might be drawn far enough over the cornea, nature was obliged to make use of a long muscle, which could not be contained in so small a place as the orbit, without being bent or inflected; and therefore the one muscle is bent upwards near the optic nerve, making an acute angle, where it passes through the perforated end

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* Todd's Cyclopædia, article, Lacrymal Organs, by the Author of this Treatise.

of the other muscle, by which means its action is greatly increased. But its action is yet more increased by the contraction of the square muscle itself, which must draw the cord or tendon of the pyramidal muscle which passes through it, through a space double of what it moves itself; and thus the membrana nictitans is extended far enough to cover the whole cornea, though its muscles are contained in a small space."

The greater or less degree of development of some particular organ, in different animals according to their wants, which the comparative anatomist so often meets with, is well illustrated by a comparison of the semi-lunar fold in man, with the third eyelid of birds, and the intermediate phases of development which the same organ presents in quadrupeds and the higher orders of reptiles. The same point is also illustrated by a comparison of the lower eyelid of man, with the larger and more moveable lower eyelid of birds and tortoises; and, especially, with the lower eyelid of frogs and some lizards, which admits of being drawn over the eye, but on account of its transparency, does not wholly interrupt vision.

Though all vertebrate animals are normally provided with eyes, there are some among them in which those organs are small, and but little developed, their habits of life not requiring much, if at all, the exercise of sight. In such cases, the skin passes right over the eyes—there are no special organs in the shape of eyelids. Examples of this congruity of design are presented to us in the blind rat and moles,—mammiferous animals which live underground; in certain scincoidians,—lizards which approach serpents in form; in the proteus and siren,—perenni-branchiate batrachian reptiles, which inhabit, the former the subterranean waters of Carniola, &c., the latter the marshes of Carolina; and in many fishes which burrow in the mud and sand.

The palpebral conformation of serpents and geckoes (reptiles of the order of lizards) may be here mentioned, as intermediate between the transparent moveable lower eyelid of certain lizards and frogs, and the simple continuation of the skin over the rudimentary eyes in such cases as those just referred to, and as equally congruous with the circumstances under which the animals are destined to pass their lives. The palpebral conformation of serpents and geckoes is this:—instead of two moveable eyelids with the usual opening between them, there is a transparent continuation of both skin and conjunctiva united, over the front of the eye, set like a spectacle-glass, as it were, in a sort of frame formed by the common skin around the margin of the orbit.

In man the eyelids and iris often act in conjunction. In some of the lower animals, there are certain points in which the iris and eyelids approximate not only in function, but even somewhat in analogous conformation. "In connexion, therefore, with the subject of the eyelids, it will not be out of place to allude to that flocculent growth of the uvea hanging from the upper pupillary margin of the iris over the transversely elongated pupil in the horse, &c., and which appears to serve the purpose, if it may be so expressed, of an internal eyelid. An analogous, but more curiously and highly developed structure—a blending as it were of the iris with some remains of the structure of the eyelids—exists in the eyes of several fishes; among others, in the skate.

" The structure alluded to is a digitated extension of the whole substance of the upper part of the iris, hanging over the pupil, which it is large enough entirely to cover. There being no intrinsic power of motion in the iris of fishes, the mechanism by which this digitated veil is drawn up from over the pupil is this:—Where the upper part of the ciliary margin of the iris is connected with the sclerotica, the latter is very flexible and is externally intimately connected with a fold or rudimentary upper eyelid which the integument forms before passing as conjunctiva over the eye. Muscular fibres are inserted into this fold at the point of connexion, and draw it upwards; the flexible part of the sclerotica of course follows this movement and the upper part of the iris, the sclerotica, so that the digitated veil is drawn up from over the pupil. In a young skate which I removed from the egg and preserved alive for some weeks, I observed that the digitated veil was kept down during the day, but was drawn up towards evening, and the large black pupil exposed." *

In the lower mammiferous animals generally, in birds and in the higher reptiles, a lacrymal gland is found, but it is small in comparison with another gland, situated at the inner and anterior part of the orbit or socket of the eye, and which is developed in direct proportion to the nictitating membrane or third eyelid, to whose functions its secretion appears to be subservient. This gland, commonly known under the name of the "gland of Harder," but which may

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* Article "Lacrymal Organs," in Todd's Cyclopædia of Anatomy and Physiology, above quoted.

be appropriately enough designated the "gland of the third eyelid," does not exist in man, in whom there is no third eyelid, nor in quadrumanous animals, which are also destitute of that organ.

The derivative lacrymal apparatus, it would appear, is for the purpose of draining off into the nose the secretion of the lacrymal gland only, and not that of the gland of the third eyelid, for it is much developed where the lacrymal gland is large, and where, as in man and quadrumanous animals, no gland of Harder is found; whilst it is said to be wanting in animals in which the lacrymal gland is absent or very small, but in which the gland of Harder is large, as in the elephant.

In the higher animals inhabiting the waters, the lacrymal organs are but little developed, whilst in the frog tribe and in fishes they are altogether wanting.

With the exception of cephalopodous mollusca, in some of which the skin around the eye forms eyelid-like folds, invertebrate animals have no eyelids properly so called. The most remarkable provisions, perhaps, met with amongst them for the protection of their eyes are:—in the snail tribe, the retractile tentacles or horns on which the eyes, which are simple, are supported,—in some at the extremity, in others, on a projection at the middle, and in others again, at their base; and, in lobsters and crabs, the peduncles, on which the eyes are supported, moving on a joint and capable of being turned down out of the way, sometimes into depressions for their reception.

The above narrated comparative anatomical details regarding the accessory parts of the organ of vision, in the lower animals, show that in small things as in great, the wisdom, power, and beneficence of God are equally manifest. "If I ascend up into heaven," says the Psalmist, praising God for his all-seeing providence, "thou art there: if I make my bed in hell, behold, thou *art there*."—Ps. cxxxix. 8.

CONCLUSION.

Great things doeth He, which we cannot comprehend.—Job xxxvii. 5.

There are yet hid greater things than these be, for we have seen but a few of his works.—ECCLESIASTICUS xliii. 32.

As already enunciated in the Introduction, it has not been the object of the preceding pages to prove the existence of God, but to celebrate His wisdom and beneficence as displayed in the senses, and especially the SENSE OF VISION.

We hope that the evidences of wise and beneficent design we have adduced, are " at least independent, unbiassed, and spontaneous," and that we have not been unsuccessful in avoiding the grave error of straining facts to make them square with our arguments, or of framing conceits of our own, and holding them up as examples of wise and beneficent design. That we may have erred sometimes in our estimate of the evidences adduced is to be admitted, but it ought at the same time to be observed that there may be much more of wise adaptation of means to ends, and much more of beneficence in the particular instances cited than we, in our ignorance, have been able, to discover. Any defect in our mode of handling the argument, therefore, must not be put down to any real defect in the nature of the argument itself.

There are, indeed, many things in the creation which we cannot comprehend,—many things, which we cannot, owing to our ignorance, perceive the end the Creator had in view in forming. In such cases, the wisdom and beneficence of the Almighty are, nevertheless, still abundantly manifest. Though we may not, for example, understand the particular end a machinist had in view in constructing a particular machine, we may still be able to perceive enough of beauty and order in its workmanship, and in the principle of its action, to satisfy us that the maker not only had *a* design, but that he was possessed of both the wisdom and power to carry it into effect. So it is in the creation; we can see that everything is wisely contrived and well made, though we cannot always fully comprehend its use, or application.

Interesting and instructive as are the instances illustrative of the wisdom and beneficence of the Almighty, above adduced from the Physiology of the Senses, it is to be repeated that there is nothing in the Creation, if rightly contemplated, which does not equally tell of God's wisdom and beneficence,—that there are, in short, "sermons in stones and good in everything." But great and good as all things are in this fair world around us, it may truly be said, with the son of Sirach, that there are yet hid greater things than these be, for we have seen but a few of God's works. Even under the present temporal dispensation, many great and good things,—signal instances of the wisdom and beneficence of the Almighty—may still remain to be, in the fulness of time, brought to light; whilst, as regards what shall be under another dispensation, "it is written, Eye hath not seen, nor ear heard, neither have entered into the heart of man, the things which God hath prepared for them that love him."—1 Cor. ii. 9.

THE END.

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